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Vehicular Crash Tests of a Slip-formed, Single Slope, Concrete Median Barrier

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This project was performed in cooperation with the US Department of Transportation, Federal Highway Administration, under the research project titled Vehicular Crash Tests of a Slip-formed, Single Slope, Concrete Median Barrier With Integral Concrete Glare Screen.

16. ABSTRACT
Two single-slope concrete median barriers were built and crash tested. Construction was accomplished by a slip-forming method. The primary difference between the two barrier designs is the vertical face angle (10.8* and 9.1* for the Texas and Type 60 profiles, respectively). Each of the two barriers was 1.42 meters tall and was reinforced by #5 rebar. At the base, the Texas barrier was 960 mm wide while the Type 60G was 610 mm wide.

A total of five crash tests was performed, two tests on a 1420 mm-tall Texas barrier, two on a 1420 mm-tall Type 60G barrier and one on an 810 mm-tall Type 70 bridge rail. (Note: The Type 70 bridge rail has the same slope face as the Type 60 barrier). The 2000P test for the Texas barrier was unsuccessful due to a vehicle guidance failure and was not repeated. The 920C tests of the barriers were supplemented with an 820C test of a Type 70 bridge rail. Tests were performed in accordance with Test level 3 of NCHRP Report 350. Details on the failed 2000P test are included in this report to demonstrate the strength of the Texas barrier. All other tests showed that both the Texas barrier and the Type 60 will perform satisfactorily. Primary damage to the vehicles consisted of the severe damage to the impacting wheel.

The Type 60G barrier is recommended for approval on California highways.

17. KEYWORDS
Barriers, Crash Test, Median Barrier, Concrete, Vehicle Impact Test, Single Slope, Glare Screen, Texas, Type 60, Type 70

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A total of five crash tests was performed, two tests on a 1420 mm-tall Texas barrier, two on a 1420 mm-tall Type 60G barrier, and one on an 810 mm-tall Type 70 bridge rail. (Note: The Type 70 bridge rail has the same slope face as the Type 60 barrier). The 2000P test for the Texas barrier was unsuccessful due to a vehicle guidance failure and was not repeated. The 820C tests of the barriers were supplemented with an 820C test of a Type 70 bridge rail. Tests were performed in accordance with Test level 3 of NCHRP Report 350. Details on the failed 2000P test are included in this report to demonstrate the strength of the Texas barrier. All other tests showed that both the Texas barrier and the Type 60 will perform satisfactorily. Primary damage to the vehicles consisted of the severe damage to the impacting wheel.

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NOTICE

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English to Metric System (SI) of Measurement

SI CONVERSION FACTORS

To Convert From	To	Multiply By
	ACCELERATION	
ft/s^2	m/s^2	0.3048
	AREA	
ft^2	m^2	0.0929
	ENERGY	
ft.lbf	Joule (J)	1.3558
	FORCE	
lbf	Newton (N)	4.4482
	LENGTH	
ft	m	0.3048
in	m	0.0254
in	cm	2.5400
	MASS	
lb	kg	0.4536
	PRESSURE OR STRESS	
psi	Pascal (Pa)	6894.76
	VELOCITY	
mph	km/hr	1.6093
ft/s	m/s	0.3048
ft/s	km/hr	1.0973

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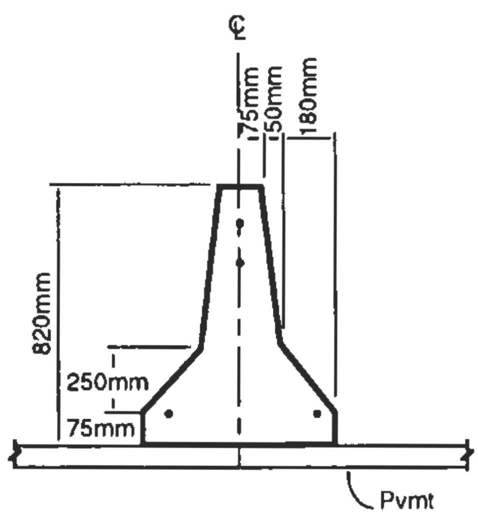
1. INTRODUCTION

1.1. Problem

All new or retrofit concrete median barriers (CMB) on California highways since the 1970's have been the standard Caltrans Type 50 median barrier, with a New Jersey safety shape profile (Figure 1.1). The Type 50 CMB is 810 mm high. This height may be reduced to 740 when a pavement overlay is placed up against it per the American Association of State Highway and Transportation Officials (AASHTO) Roadside Design Guide[1]. Thicker overlays or additional overlays increase the chance of an impacting vehicle climbing over the top of the barrier. They also modify significantly the height of the breakpoint (and thus the basic geometry) of the two different slopes on the face of the barrier. Hence, when the existing Type 50 CMB will be reduced in height below 745 mm due to overlays, it must be completely replaced at a substantial expenditure of time and money. A second problem is that the 810-mm high Type 50 CMB does not provide glare protection, and there is no Department-approved design for new CMB that incorporates a concrete glare screen.

Figure 1.1 - Type 50



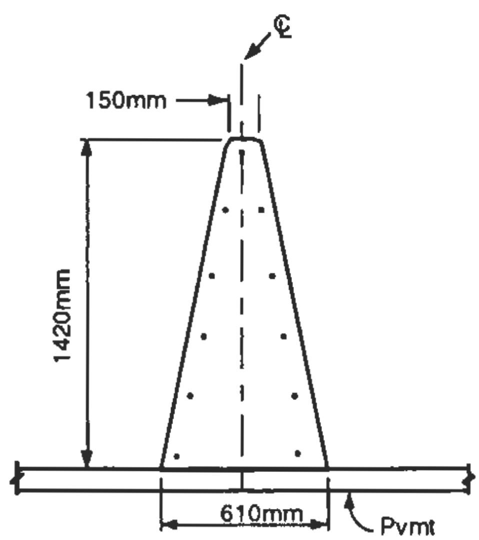
1.2. Objective

The objectives of these tests were:

a. To determine whether a lightly reinforced, 1420 mm, single-slope concrete median barrier with integral glare screen (Figure 1.2) will satisfy the requirements of National Cooperative Highway Research Program Report 350 (NCHRP Report 350[2], test level 3), the crash test guidelines adopted by both FHWA and Caltrans.

b. To establish whether the single-slope barrier provides an equivalent or better alternative to the Type 50 CMB currently in use.

Figure 1.2 - Type 60G



1.3. Background

Concrete safety shape barriers were approved for use in narrow medians in California in 1971. This barrier has long been the standard for new installations and for replacement of older types. Approximately one-half of the total median barrier inventory in California are concrete barrier. The Type 50 Concrete Median Barrier has the highest percentage of unreported accidents since, in flat angle collisions with this barrier (under 10°), most vehicles are redirected by the safety shape with minimal or no damage and can be driven away. Concrete barriers are rarely damaged, and then only for a few feet in length. Hence, concrete barriers cause the least expenditures of time and cost for repairs, and cause the least disruption to adjacent traffic while being repaired. This is also the cleanest barrier, with no projections to collect debris. Accident performance by the Type 50 CMB has been comparable to that of the more flexible types of median barrier in narrow medians[3].

Several concrete median barrier designs have been tested by Caltrans and other agencies in recent years. These have mostly been taller versions of the New Jersey and the Configuration F profiles[4]. None of these designs meet our need for overlaying the pavement without re-adjusting the median barrier. The only CMB in the AASHTO Roadside Design Guide is the safety shape (New Jersey profile) barrier, which also fails to meet our overlay needs.

A pre-cast single-slope concrete median barrier has been successfully designed and tested in Texas[5,6]. The Texas design is 610 mm wide at the base, 200 mm wide at the top, and 1070 mm high. This gives it a face slope of 10.8°. This slope was determined to be *optimal* after running several computer simulations of vehicle crashes.

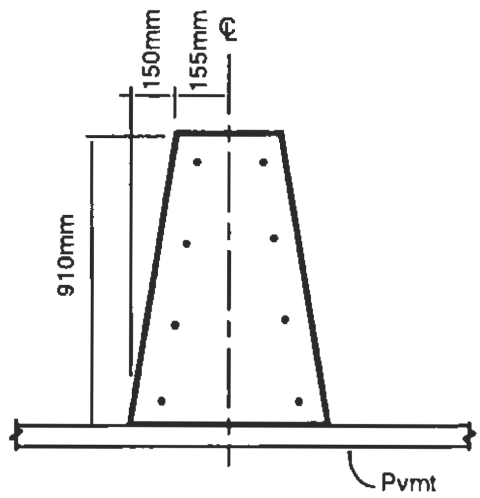
The minimum height recommended for glare screen is 1270 mm[7]. Caltrans proposes to use a single slope barrier that is initially 1420 mm high to provide glare protection and allow for future overlays up to 150 mm. If the same 10.8° slope and 610-mm base used in the Texas design were to be maintained, the top of a 1420 mm high barrier would only be 70 mm wide which is very thin and cannot be slip-formed. If a top width of 150 mm is used, the base width then becomes 690 mm. California has many narrow medians that are only 610 mm wide. A wider CMB base would infringe on the required minimum shoulder widths and necessitate special exemptions for each job. Therefore, it is proposed to set the barrier base width at 610 mm, top width at 150 mm, and change the face slope from 10.8° to 9.1° for the 1420-mm high design. (Figure 1.2)

The Texas Transportation Institute (TTI) reports[5,6] conclude that 10.8° is the optimum slope for the face of a single slope barrier. This conclusion was based on the selection of the face slope which performed best among three different slopes selected for study. Nevertheless, TTI performed a limited number of computer simulations and full scale crash tests, and there was not close agreement between the two when vehicle roll and accelerations were compared. Further, in the crash test, the largest vehicle experienced significant climb and roll. Therefore, 10.8° may not be an optimum design, at least for some impact conditions. The slightly steeper slope of the proposed Caltrans design (9.1°) may be preferable to reduce climb and roll of some impacting vehicles.

A large percentage of Type 50 CMB is slip-formed, which is a quick, economical construction process. It seems desirable to adopt a new CMB design that can be readily slip-formed to take advantage of the benefits afforded. A barrier height of 1420 mm may be close to the upper limit for slip-forming this type of structure. This project provides the opportunity to evaluate the slip-forming process for a 1420-mm high CMB with a 9.1° face slope.

The Caltrans Division of Traffic Operations has stated that the majority of new CMB will be the 1420-mm high design because much of it will be placed in narrow medians where glare screen is warranted. Nevertheless, Caltrans also proposes to include in their Standard Plans a similar, lower-height barrier for locations where glare screen is not warranted which will be 910 mm high with a 610 mm base, a 310-mm top width and a 9.1° face slope (Figure 1.3). The 910-mm height will allow overlays several inches thick without reducing the basic crashworthiness of the barrier. The 9.1° face slope should cause the same response for impacting vehicles as the 9.1° slope on the 1420-mm high barrier. The 310-mm top width will allow the addition of a retrofit concrete glare screen identical in shape to the top of the 1420-mm high barrier, if needed in the future. If the crash tests on the 1420-mm barrier are successful, a judgment will be made on the crashworthiness of the 910-mm high barrier.

Figure 1.3 - Type 60



1.4. Literature Search

A literature search using the Transportation Research information System, the national Transportation Information Service, and the Compendex Plus databases was conducted to find research reports or publications related to the objectives of this project. References 5 and 6 were the only two found each of which dealt with the Texas barrier.

1.5. Scope

A total of five crash tests were performed and evaluated for Test Level 3 according to NCHRP Report 350. The Texas barrier (10.8° face) and the Type 60G (9.1° face) were each 1420 mm tall, while the Type 70 (also a 9.1° face) was 810 mm tall. Each barrier was tested under the 820C and the 2000P impact conditions (see Table 1-1). However, the 2000P test for the Texas profile was unsuccessfully performed due to a problem with the guidance system (this was not repeated).

Table 1-1 - Target Impact Conditions

Test #	Barrier type	Vehicle Mass (kgs)	Vehicle Speed (km/hr)	Impact Angle (deg)
531	Texas Barrier	820	100	20
532	Texas Barrier	2000	100	25
533	Type 60	820	100	20
534	Type 60	2000	100	25
511*	Type 70†	820	100	20

* Test 511 was added to the test matrix in order to replace Test 533 which had speeds too low for proper consideration under NCHRP Report 350 as a validation test.

† The Type 70 is a bridge rail having the same slope as the Type 60.

2. TECHNICAL DISCUSSION

2.1. Test Conditions - Crash Tests

2.1.1. Test Facilities

Each of the crash tests was conducted at the Caltrans Dynamic Test Facility in West Sacramento, California, near Sacramento. The test area is a large, flat, asphalt concrete surface. There were no obstructions nearby except for a 2-m high earth berm 30 m downstream from the closest test barrier.

2.1.2. Test Barriers

2.1.2.1. Design

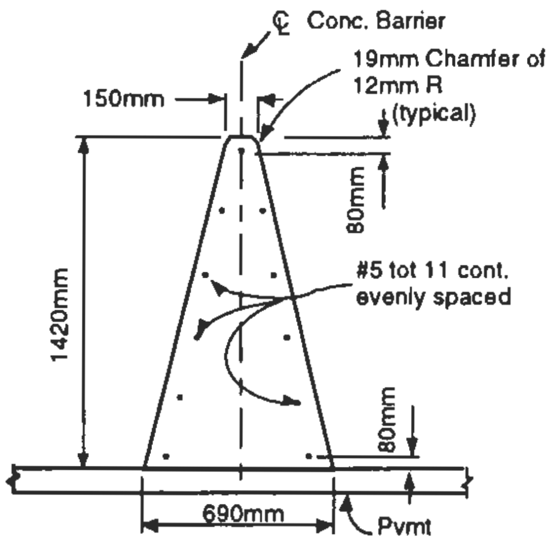
2.1.2.1.1. Texas Profile Single Slope Barrier

The shape is the only difference between the Texas and the Type 60G barriers (10.8 vs 9.1 degree side slopes, respectively). As discussed in the Background section of this report, the design of the Texas barrier was developed through the use of computer optimization. The Texas profile barrier tested in this report had the same profile that was tested for The Texas Transportation Institute. In addition, the Texas barrier tested was designed with a concrete glare screen on the top of the barrier, which meant having to design a barrier with the dimensions seen in Figure 2.1. The side slope of the tested "Texas" barrier is the same as an actual Texas barrier, but the tested version is thicker than the standard Texas barrier by 80 mm (690 mm vs 610 mm base width) for the purpose of accommodating a glarescreen.

The decision to design a barrier that could be slip-formed was made in order to make a smooth transition from the slip-formed Type 50 concrete median barrier which is California's primary concrete median barrier. Compared to the 810 mm tall Type 50, the Texas barrier with glarescreen is more difficult to slip-form. The concrete mix for the Texas barrier was designed with a zero slump in order to accommodate the steep walls that would be produced during slip-forming.

Number 5 reinforcing steel was used in the barrier to provide tensile strength during the slip-forming operation and during vehicle impact.

Figure 2.1 - Texas Barrier



CONCRETE BARRIER
TEXAS PROFILE
Monolithic concrete
barrier / glare screen

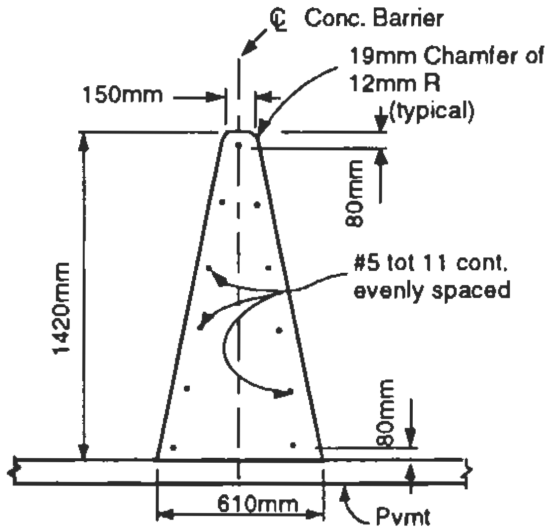
2.1.2.1.2.Type 60G Single Slope Barrier

The shape is the only difference between the Texas and the Type 60G barriers (10.8 vs 9.1 degree side slopes, respectively). This difference in the profile angle was made in order to accommodate the need for a median barrier that would be a direct replacement for the Type 50 concrete median barrier, which is only 610 mm wide at the base. In order to maintain the 150 mm top width required for strength, the barrier had to have a 9.1 degree face (steeper than the Texas profile).

The concrete mix for the taller barrier was designed with a zero slump in order to accommodate the steep walls that would be produced during slip-forming.

Number 5 reinforcing steel was used in the barrier to provide tensile strength during the slip-forming operation and during vehicle impact.

Figure 2.2 - Type 60G



CONCRETE BARRIER
TYPE 60G
Monolithic concrete
barrier / glare screen

2.1.2.2. Construction

Both the constructed Texas and the Type 60G barriers were 50 meters in length. The as-built plans are shown in Appendix 7.6. The slip-forming machinery included the new mule used to slip-form the barriers is shown in Figure 2.3 and Figure 2.4. Each barrier was slip-formed in a single pass and was done so in accordance with Section 83-2.02 (3B) of the Caltrans Standard Specifications[8]. The slip-forming machinary used, including the "new mule", is shown in FiguresFigure 2.3 and Figure 2.4

There were some problems with the slip-forming operation at the beginning of the construction of the first barrier (the Type 60G). The new operation had never been tested. The first half meter of the first slip-forming operation developed problems with concrete settling and separation. It was discovered that the slump was too high, so the contractor lowered the amount of water in the concrete and changed the location of the vibrators. The next couple of meters proved to be a "testing ground" for the contractor to learn the proper management of the mule and mix design.

Even though the contractor eventually mastered the nuances of the slip-forming operation, considerable patch work was required in order to get the barriers to conform to the required profiles. Most of the patching had to be done at the ends of the barriers where the mule had to be put on or taken off the barriers. Plywood forms had to be used at the beginning of each slip-forming operation due to a lack of proper consolidation of the concrete before the mules were first moved. Forms also had to be used at the end of each operation due to the need for vertical steel reinforcement. The mules had to be lifted vertically off the barriers, then barrier end forms set in place before the anchors were cast.

After the construction was complete, there was some question as to whether or not the barriers were true to their design profiles (See Appendix 7.6). There were sections that bowed outward from the slumping of the tall barrier. Taking into account the fact that barriers as tall and vertical as these had never been constructed using slip-forming techniques before, it was expected that there would be problems. however, it is also anticipated that these problems will be addressed as contractors gain experience in using the new equipment. Figure 2.3 through Figure 2.10 show the slip-forming equipment and the barrier construction.

Figure 2.3 - The Slip-forming Mule And Form

Figure 2.4 - The Form Separated From The Mule

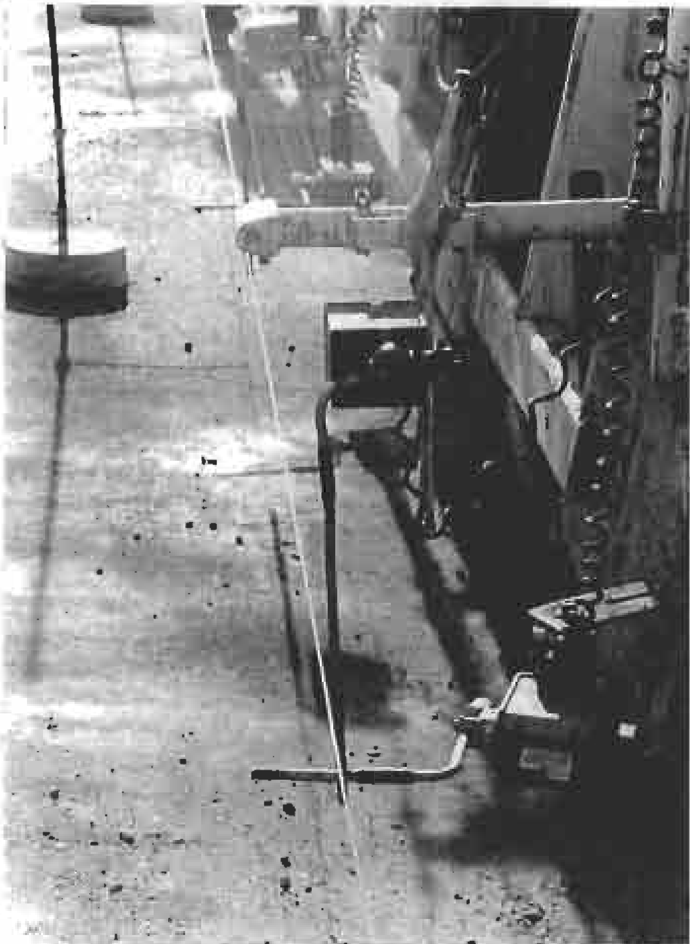


Figure 2.5 - The Mule Was Guided By Sensors (Both Vertically And Laterally)

Figure 2.6 - The Rebar Was Guided Into The Proper Position During Slip-forming.

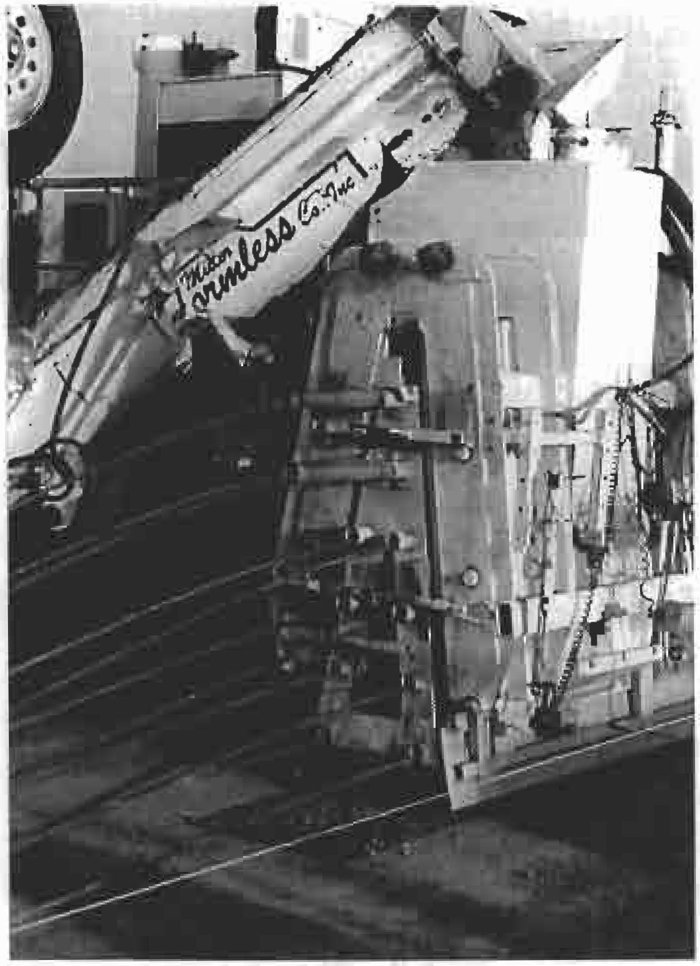


Figure 2.7 - The Leading Edge Of The Slip-forming Operation.

Figure 2.8 - A Concrete Truck Lead The Slip-forming Operation

Figure 2.9 - The Ends Could Not Be Slipformed Because Of The Vertical Rebar.

Figure 2.10 - The End Forms Were Held In Place With Bar Clamps.

2.1.3. Test Vehicles

The test vehicles complied with NCHRP Report 350[2]. For all tests, the vehicles were in good condition and free of major body damage and were not missing structural parts. All equipment on the vehicles was standard. The engines were front mounted. The vehicle inertial masses were within acceptable limits (Table 2-1) for all but test 531.

Table 2-1 - Test Vehicle Masses

Test No.	Vehicle	Ballast (kg)	Test Inertial (kg)
531*	1990 Tercel	0	865
532	1991 Chevy	0	2000
533	1990 Tercel	0	845
534	1991 Chevy	0	2000
511	1992 Geo	0	843

* The vehicle for test 531 was instrumented, then weighed. The vehicle test inertial mass was 865 kg (20 kg over the limit set by NCHRP Report 350). Since test 531 was for comparison to the Type 60G barrier, and not for validation, the additional 20 kg was deemed acceptable.

The vehicles were self-powered; a speed control device maintained the desired impact speed once it was reached. Remote braking was possible at any time during the test. Guidance of the vehicle was achieved with a rail guidance system. In tests 531, 532, and 533, the vehicle steering wheels were unrestrained. In test 534 a bungie cord was attached to the vehicle's steering wheel in order to prevent oscillation in the steering system. A short distance before the point of impact, each vehicle was released from the guidance rail and the ignition was turned off. A detailed description of the test vehicle equipment and guidance systems is contained in Appendix 7.1 and 7.2.

All impacts were on the left (driver) side of the vehicles, with the exception of test 511, which was intended to augment test 533. The impact for test 511 was on the right side of the vehicle.

2.1.4. Data Acquisition System

The impact phase of each crash test was recorded with several high speed movie cameras, one normal speed movie camera, one black and white sequence camera and one color slide sequence camera. The test vehicles and test barriers were photographed before and after impact with a normal speed movie camera, a black and white still camera and a color slide camera. A film report of this project was assembled using edited portions of the movie coverage. A supplemental film report containing test 511 is also available.

Three sets of orthogonal accelerometers were mounted in each vehicle (two at the center of gravity and one at 600 mm behind the center of gravity. Additional accelerometers were placed in the vehicles for the purpose of obtaining supplemental data for finite element analysis (not included in this report). Rate gyro transducers were also placed at the center of gravity of each vehicle to measure the pitch, roll and yaw of the vehicles. The accelerometer data were used in calculating the occupant impact velocities and ridedown accelerations.

An anthropometric dummy with three accelerometers mounted in its head cavity was placed in the driver's seat of the vehicles used in tests 531, 533 and 511 to obtain motion and acceleration data. The dummy, a Hybrid III built to conform to Federal Motor Vehicle Safety Standards by the Sierra Engineering Company, simulated a 50th percentile American male weighing 75 kg. In each test, the dummy was placed in the driver's seat and was restrained with lap and shoulder belts.

A digital transient data recorder (TDR), Pacific instruments model 5600 was used to record electronic data in the tests. The digital data were analyzed using a laptop computer.

2.2. *Test Results - Crash Tests*

A film report with edited footage from tests 531-534 has been compiled and is available for viewing.

2.2.1. Test 531 - 865 kg / 91.8 km/h / 19.8° - Texas Barrier

The planned test conditions were: 820 kg / 100 km/h / 20°. The Data Summary Sheet and photos taken before, during and after impact are shown in Figure 2.11 through Figure 2.16.

The speed of the vehicle for test 531 was 8 km/h lower than the target speed due to miscalculating the distance required to achieve the necessary speed.

2.2.1.1. Impact Description - 531

The measured impact speed was 91.8 km/h with an angle of 19.8 degrees. Impact with the barrier occurred 26.8 m from the upstream end of the barrier. Contact with the barrier continued for 2.4 m before exiting. The vehicle made a mild arc to the right before coming to a stop approximately 25 m from the barrier.

During the initial impact with the barrier, the vehicle's front wheels were abruptly forced to the right. The vehicle's left front suspension was broken by the impact. All four wheels of the vehicle rose off the ground about 250 mm while the vehicle rolled slightly to the left. When all four wheel were back on the ground, the left front wheel turned sharply to the left. However, the vehicle's front right wheel continued to track as the vehicle made an arc to the right.

The vehicle remained upright throughout and after the collision. The exit angle and speed of the car were 6.6 degrees and 83 km/h, respectively. The brakes were applied 1.88 seconds after impact.

Figure 2.11 - Vehicle 531 At The Barrier Impact Location

Figure 2.12 - Vehicle 531 At The Barrier Impact Location (close-up)

Figure 2.13 - The Right Side Of Vehicle 531

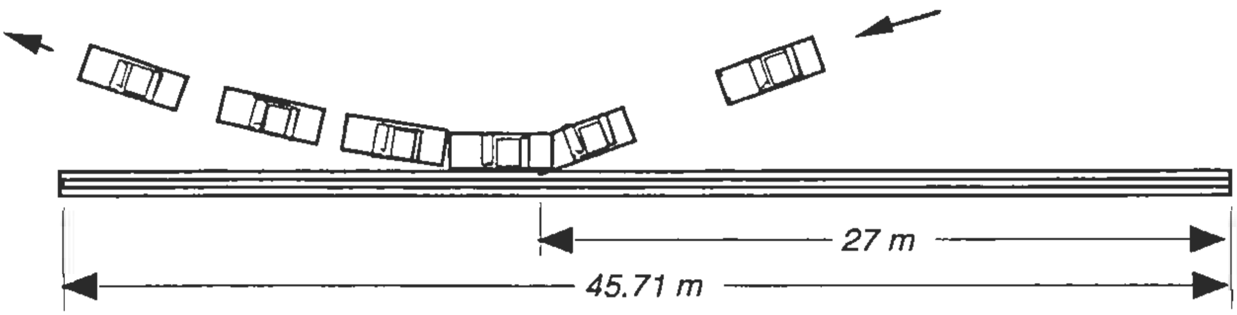
Figure 2.14 - The Left Profile Of Vehicle 531

Figure 2.15 - Test 531 Scuff Marks On The Texas Barrier

Figure 2.16 - Test 531 Data Summary Sheet

t=0.00 sec t=0.05 sec t=0.10 sec t=0.15 sec

t=0.20 sec t=0.25 sec t=0.30 sec t=0.35 sec



Test Barrier

Type:	Texas Barrier w/glare screen
Length:	50 meters

Test Date: February 9, 1995

Test Vehicle:

Model:	1990 Toyota Tercel
Inertial Mass:	865 kg
Impact / Exit Velocity:	91.8 km/h / 83 km/h
Impact / Exit Angle:	19.8° / 6.6°

Test Dummy

Type:	Part 572 50th percentile male
Weight / Restraint:	165 lbs / lap and shoulder
Position:	Driver's Seat

Test Data:

Occ. Impact Velocity (Long / Lat):	4.60 m/s / -6.83 m/s
Ridedown Acceleration (Long / Lat):	-2.6g / 11.3g
Max. 50 ms Avg. Accel (Long / Lat):	-7.2g / 12.8g
Exterior: VDS/CDC[9]	FL-3, LD-5 / 12LFEK2
Interior: OCDI[10]	LF0000000

Barrier Damage: Only superficial scuffing

2.2.1.2. Vehicle Damage - 531

Damage to the vehicle was moderate. The front left corner of the vehicle sustained the most damage, but additional sheet metal crushing and scraping occurred along the entire left side of the vehicle.

The initial impact caused the bumper to turn inward toward the tire. The front left tire impacted the barrier with enough force to tear it from the suspension, leaving only the strut to hold the wheel assembly onto the frame. Near the point of impact the hood was slightly crumpled.

As the vehicle turned parallel to the barrier, the sheet metal on the entire left side came into contact with the barrier face. The rear left tire rubbed along the barrier, but was not damaged beyond moderate scuffing.

2.2.1.3. Barrier Damage - 531

Barrier damage was cosmetic only, consisting of scrapes and tire marks. Both left tires left marks along the face of the barrier for the three to four meters of contact. Small amounts of concrete spalled from the face of the barrier where the vehicle's sheet metal made contact.

2.2.1.4. Dummy's Response - 531

The dummy was lap and shoulder belted. At impact, the dummy's head moved out of the driver's side window about 50 mm. The dummy did not impact the barrier face. The dummy remained upright and secure during the rest of the test. The final resting position of dummy was upright in the driver's seat.

2.2.2. Test 532 - 2000 kg / 71.5 km/h / 53° - Texas Barrier

The planned test conditions were: 2000 kg / 100 km/h / 25°. The Data Summary Sheet and photos taken before, during and after impact are shown in Figure 2.17 through Figure 2.23.

Note: Although the test conditions were not met due to problems with the vehicle's guidance system, this test is included in this report because the test results can be of benefit in the final analysis of the Texas barrier.

2.2.2.1. Impact Description - Test 532

Due to problems with the guidance system the vehicle impacted at an angle and speed that were significantly different from the planned impact conditions. The vehicle's intended path to impact started with a 100 m straight section into a 100 m curved section (800 m radius turn to the left), and ended with a 50 m straight section into the barrier About 150 m before impact, the vehicle's steering system began to oscillate and the vehicle started shifting from side to side. As the vehicle came out of the planned 800-m radius turn to the left, it appeared to be recovering from the side-to-side motion. However, the recovery was incomplete and the vehicle started to lose traction. The vehicle's rear tires skidded into the guidance rail, causing the rail to break loose. At 0.6 seconds before impact the guidance arm broke loose from both the guide rail and the vehicle. The emergency brake was applied 0.25 seconds before impact. The impact speed, angle of impact and yaw angle were 71.5 km/h, 53 degrees, and -19 degrees, respectively. Impact occurred 3 m upstream from the intended impact point.

The front left corner of the vehicle was immediately pushed in. The front of the vehicle rose off the ground as the vehicle slid along the barrier for about four meters. When the vehicle lost contact with the barrier the front end regained contact with the ground and the vehicle started tracking again. The exit speed and angle were 33 km/h and 2 degrees, respectively.

Figure 2.17 - The Upstream View Of The Texas Barrier And Its Profile

Figure 2.18 - Vehicle 532 Bumper At The Proposed Barrier Impact Location

Figure 2.19 - The Right Side Of Vehicle 532

Figure 2.20 - Broken Guidance Rail And The Final Impact Location For Test 532

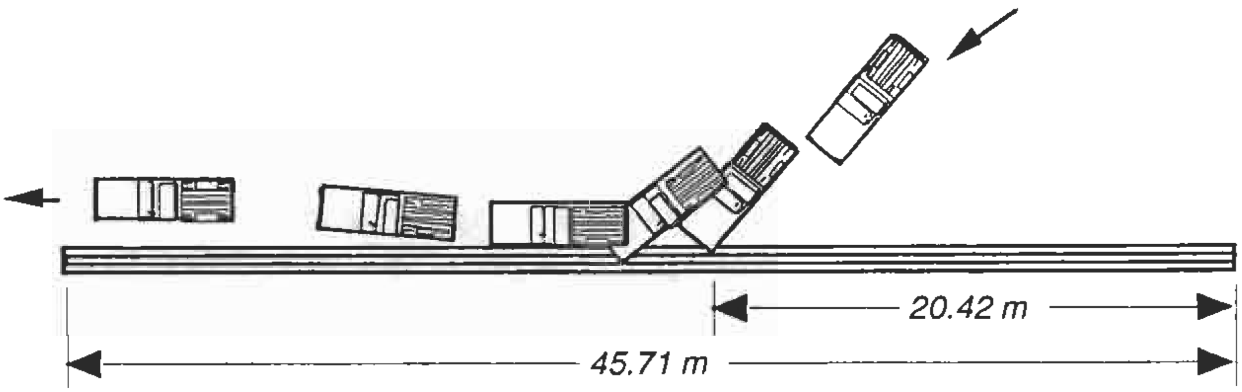
Figure 2.21 - Test 532 Scuff Marks At The Impact Location

Figure 2.22 - Test 532 Barrier Impact On The Nose Of A Second Barrier

Figure 2.23 - Test 532 Data Summary Sheet

t=0.00 sec | t=0.05 sec | t=0.10 sec | t=0.15 sec

t=0.20 sec | t=0.25 sec | t=0.30 sec | t=0.35 sec



Test Barrier
- Type: Texas Barrier w/glare screen
- Length: 50 meters

Test Date: March 16, 1995

Test Vehicle:
- Model: 1991 Chevy pickup
- Inertial Mass: 2000 kg
- Impact / Exit Velocity: 71.5 km/h / 33 km/h
- Impact / Exit Angle: 53° / 2°
- Impact Yaw angle -19°

Test Dummy
- Type: none
- Weight / Restraint: NA
- Position: NA

Test Data
- Occ Impact Velocity (Long / Lat): not avail.
- Ridedown Acceleration (Long / Lat): not avail.
- Max. 50 ms Avg. Accel (Long / Lat): not avail.
- Exterior: VDS/CDC[9] FC-5, FL-4, LD-5 / 12LFEK4
- Interior: OCDI[10] LF1032122

Barrier Damage: Only superficial scuffing

2.2.2.2. Vehicle Damage - 532

Damage to the vehicle was severe. The front left corner of the vehicle sustained the most damage, but additional sheet metal crushing and scraping occurred along the entire left side of the vehicle.

The initial impact caused the bumper to tear away from the vehicle. The front left tire impacted the barrier with enough force to tear it from the suspension, leaving only the strut to hold the wheel assembly onto the frame.

A large portion of the vehicle damage occurred after the initial impact when the vehicle ran into the blunt end of the Type 60G barrier which was being prepared for the next test and was just downstream from the Texas Barrier.

2.2.2.3. Barrier Damage - 532

Barrier damage was cosmetic only, consisting of scrapes and tire marks. Small amounts of concrete spalled from the face of the barrier where the vehicle's sheet metal made contact.

2.2.3. Test 533 - 845 kg /92.9 km/h / 19.5° - Type 60G

The planned test conditions were: 820 kg / 100 km/h / 20 degrees. The Data Summary Sheet and photos taken before, during and after impact are shown in Figure 2.24 throughFigure 2.30.

The speed of the vehicle for test 533 was 7 km/h lower than the target speed due to miscalculating the distance required to achieve the necessary speed.

2.2.3.1. Impact Description - 533

The measured impact speed was 92.9 km/h with an angle of 19.5 degrees. Impact with the barrier occurred 32.0 m from the upstream end of the barrier. Contact with the barrier continued for 2.2 m before exiting. The vehicle made a mild arc to the right before coming to a stop approximately 20 m from the end of the barrier.

During the initial impact with the barrier the vehicle's front wheels were abruptly forced to the right. The vehicle rose off the ground about 250 mm with a slight roll to the left. As in test 531, the vehicle's front left suspension was broken and the left front wheel turned sharply to the left once all four wheels were back on the ground. However, the vehicle's front right wheel continued to track as the vehicle made an arc to the right.

The vehicle remained upright throughout and after the collision. The exit angle and speed of the car were 6.5 degrees and 83.1 km/h, respectively. The brakes were applied 1.88 seconds after impact.

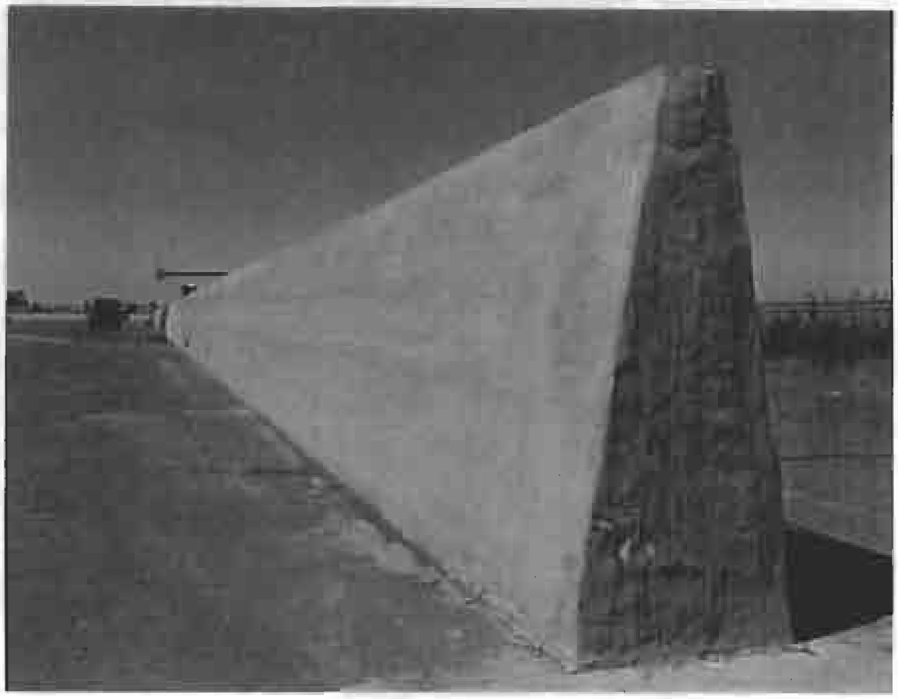


Figure 2.24 - The Face Of The 60G Barrier and Its Profile

Figure 2.25 - Vehicle 533 And The 60G Barrier

Figure 2.26 - The Right Side Of Vehicle 533 W/Guide-Arm Attached

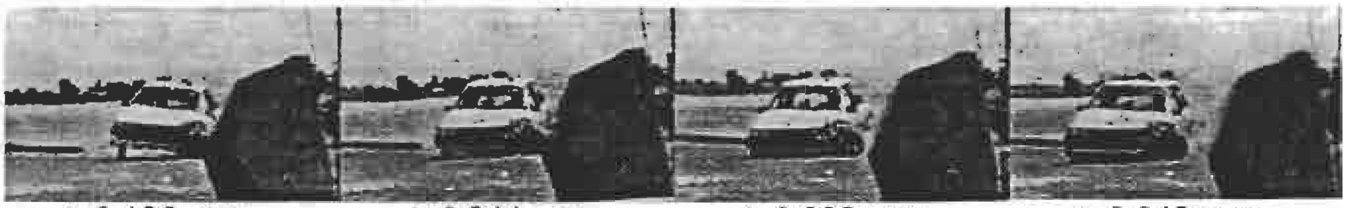
Figure 2.27 - Test 533 Scuff Marks On The 60G Barrier

Figure 2.28 - The Front Left Of Vehicle 533 And The Damaged Wheel Assembly

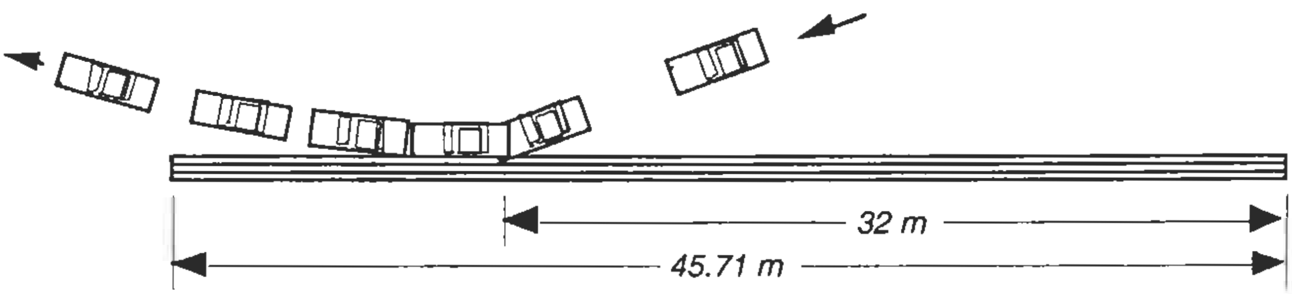
Figure 2.29 - The Left Side Of The Damaged 533 Vehicle

Figure 2.30 - Test 533 Data Summary Sheet

t=0.049 sec t=0.098 sec t=0.146 sec



t=0.195 sec t=0.244 sec t=0.293 sec t=0.342 sec



Test Barrier		
Type::	Type 60G	
Length:	50 meters	
Test Date:	June 7, 1995	
Test Vehicle:		
Model::	1990 Toyota Tercel	
Inertial Mass:	845 kg	
Impact / Exit Velocity:	92.9 km/h / 79.4 km/h	
Impact / Exit Angle:	19.5° / 6.5°	
Test Dummy:		
Type:	Part 572 50th percentile male	
Weight / Restraint:	74.8 kg / lap and shoulder	
Position:	Driver's Seat	
Test Data:		
Occ. Impact Velocity (Long / Lat):		4.72m/s / -7.9m/s
Ridedown Acceleration (Long / Lat):		-2.1g / 16.7g
Max. 50 ms Avg. Accel (Long / Lat):		-7.2g / 14.2g
Exterior: VDS/CDC[9]		FL-3, LD-5 / 11LFEK2
Interior: OCDI[10]		LF1011144
Barrier Damage:		Only superficial scuffing

2.2.3.2. Vehicle Damage - 533

Damage to the vehicle was moderate, and nearly identical to the vehicle damage incurred in test 531. The front left corner of the vehicle sustained the majority of the damage. There was additional sheet metal crushing and scraping along the left side of the vehicle.

The initial impact caused the bumper to turn inward toward the tire. The front left wheel assembly was torn from the suspension, leaving only the strut to hold the assembly onto the vehicle frame. Near the point of impact the hood was slightly crumpled.

As the vehicle turned parallel to the barrier, the sheet metal on the entire left side came into contact with the barrier face. The rear left tire rubbed along the barrier, but was not damaged beyond moderate scuffing.

2.2.3.3. Barrier Damage - 533

Barrier damage was cosmetic only, consisting of scrapes and tire marks. Both left tires left marks along the face of the barrier for the three to four meters of contact. Small amounts of concrete spalled from the face of the barrier where the vehicle's sheet metal made contact.

2.2.3.4. Dummy's Response - 533

The dummy was lap and shoulder belted. At impact, the dummy's head moved out of the driver's side window about 50 mm. There was no impact between the dummy and the barrier face. The dummy remained upright and secure during the rest of the test. The final resting position of dummy was upright in the driver's seat.

2.2.4. Test 534 - 2000 kg / 97.7 km/h / 25.2° - Type 60G

The planned test conditions were: 2000 kg / 100 km/h / 25°. The Data Summary Sheet and photos taken before, during and after impact are shown in Figure 2.31 through Figure 2.34.

2.2.4.1. Impact Description - Test 534

The measured impact speed was 97.7 km/h with an angle of 25.2 degrees. Impact with the barrier occurred 17.7 m from the upstream end of the barrier. Contact with the barrier continued for 6.7 m before exiting. The vehicle made a mild arc to the right before coming to a stop approximately 25 m from the barrier.

Vehicle behavior was similar to tests 531 and 533. During the initial impact with the barrier the vehicle's front wheels were abruptly forced to the right and the vehicle rose off of the ground about 250 mm with a slight roll to the left. As before, the vehicle's front left suspension was broken and the attached wheel turned sharply to the left. The vehicles front right wheel, however, continued to track as it made the arc to the right.

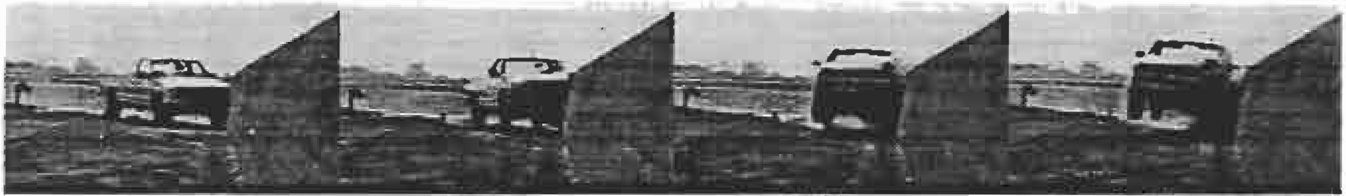
The vehicle remained upright throughout and after the collision. The exit angle and speed of the car were 6.5 degrees and 83.1 km/h, respectively. The brakes were applied 2.25 seconds after impact.

Figure 2.31 - Vehicle 534 At The Impact Location With The Guide-Arm Attached

Figure 2.32 - Test 534 Bumper Location On The 60G Barrier

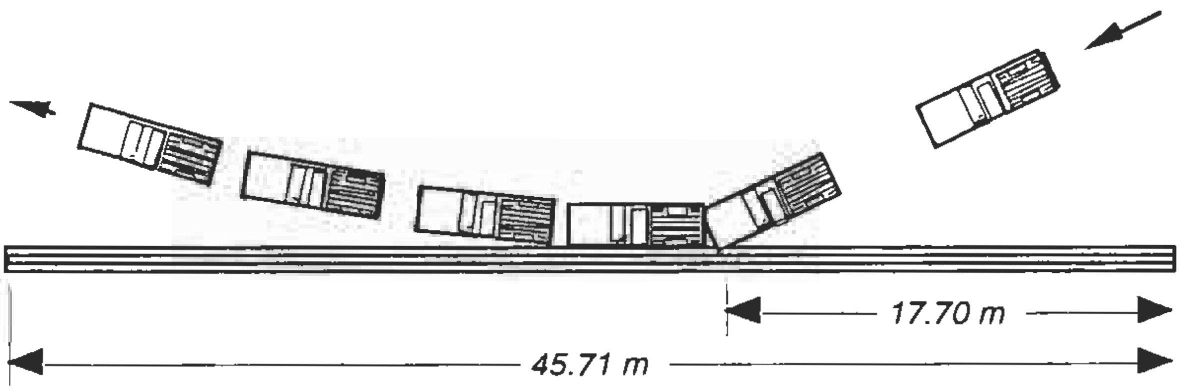
Figure 2.33 - The 60G Barrier At The Impact Location For Test 534

Figure 2.34 - Test 534 Data Summary Sheet



t= 0.00 sec   t= 0.05 sec   t= 0.10 sec   t= 0.15 sec

t= 0.20 sec   t= 0.25 sec   t= 0.30 sec   t= 0.35 sec



Test Barrier
- Type: Type 60G
- Length: 50 meters

Test Date: November 28, 1995

Test Vehicle:
- Model: 1991 Chevy pickup
- Inertial Mass: 2000 kg
- Impact / Exit Velocity: 97.7 km/h / 83.1 km/h
- Impact / Exit Angle: 25.2° / 6.5°

Test Dummy:
- Type: None
- Weight / Restraint: NA
- Position: NA

Test Data:
- Occ. Impact Velocity (Long / Lat): 6.8 m/s / -9.51 m/s
- Ridedown Acceleration (Long / Lat): -6.7g / 2.3g
- Max. 50 ms Avg. Accel (Long / Lat): -8.9g / 15.7g
- Exterior: VDS/CDC[9] FL-3, LD-4 / 12LFEK3
- Interior: OCDI[10] LF1111131

Barrier Damage: Only superficial scuffing

2.2.4.2. Vehicle Damage - Test 534

Damage to the vehicle was virtually the same as the damage reported in tests 531 and 533. The front left corner of the vehicle sustained the most damage, with additional sheet metal crushing and scraping occurring along the left side of the vehicle. The initial impact caused the bumper to turn inward toward the tire. The front left tire impacted the barrier with enough force to tear the wheel assembly from the suspension and force it into the rear of the fender well, leaving only the strut to hold the assembly onto the frame. The hood was slightly crumpled near the point of impact.

As the vehicle turned parallel to the barrier, the sheet metal on the entire left side came into contact with the barrier face. The rear left tire rubbed along the barrier, but was not damaged beyond moderate scuffing.

2.2.4.3. Barrier Damage - Test 534

Barrier damage was cosmetic only, consisting of scrapes and tire marks. Each of the impacting tires left marks along the face of the barrier for the three to four meters of contact. Small amounts of concrete spalled from the face of the barrier where the vehicle's sheet metal made contact.

2.2.5. Test 511 - 920 kg / 104.1 km/h / 20.0° - Type 70 Bridge Rail

This test, which was conducted as part of a separate study, was used to augment tests 531 and 533, since the vehicle impact speeds in those tests were somewhat low relative to the speeds recommended in NCHRP Report 350. The face of the concrete bridge rail which was impacted in test 511 had exactly the same slope (9.1°) as the Type 60G barrier which was impacted in test 533. Although the bridge rail was not as tall as the Type 60G barrier (810 mm vs. 1420 mm), the two structures were considered to be essentially the same for crash testing purposes.

The planned test conditions for test 511 were: 820 kg / 100 km/h / 20°. The Data Summary Sheet and photos taken before, during and after impact are shown in Figure 2.35 through Figure 2.43.

2.2.5.1. Impact Description - Test 511

The measured impact speed was 104.1 km/h with an angle of 20.0 degrees. Impact with the barrier occurred 11.5 m from the upstream end of the 23 m long bridge rail. Contact with the bridge rail continued for 6.5 m before exiting. While the vehicle was in contact with the barrier, an aluminum tube (part of guidance system) struck the front left section of the hood, but did not noticeably affect the outcome of the test. The vehicle went relatively straight after leaving the bridge rail. The stopping point for the vehicle was approximately 60 m from the exit location.

During the initial impact with the bridge rail the vehicle's front wheels were abruptly forced to the left. Unlike tests 531 and 533, the test vehicle's impacting wheel did not turn under the body. One or more of the vehicle's wheels maintained contact with the ground at all times.

The vehicle remained upright throughout and after the collision. The exit angle and speed of the car were 12.1 degrees and 92 km/h, respectively. The brakes were applied 0.81 seconds after impact.

Figure 2.35 - The Down Stream View Of The Type 70 Barrier With Vehicle 511

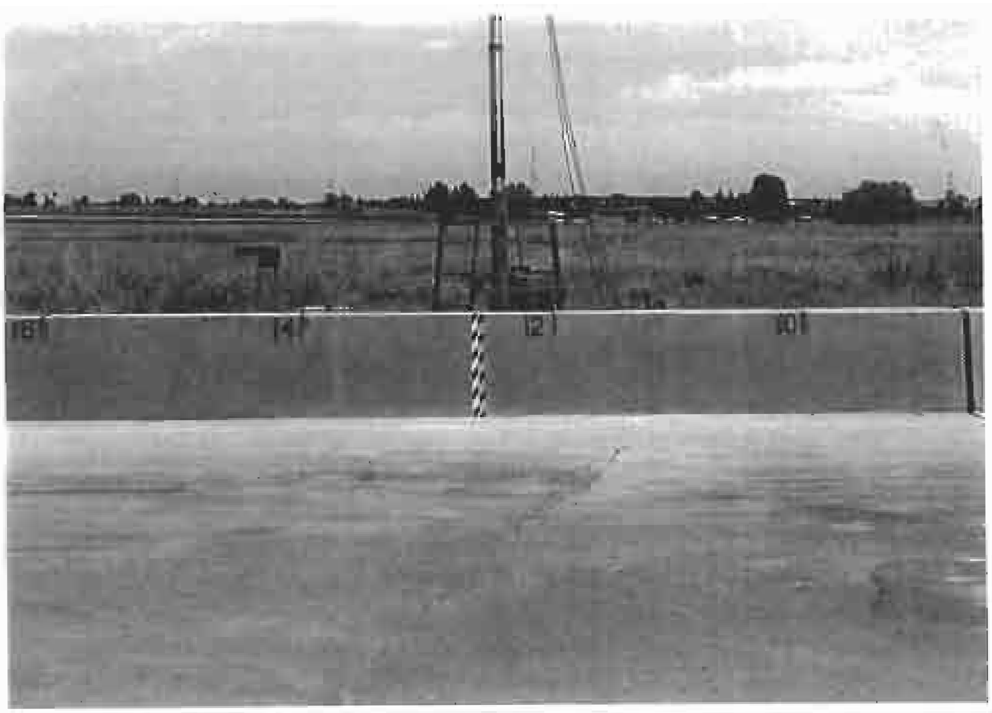


Figure 2.36 - The Side View Of The Type 70 Barrier At The Impact Location

Figure 2.37 - Front View Of Vehicle 511

Figure 2.38 - Side View Of Vehicle 511

Figure 2.39 - Right Front Of Vehicle 511 After Impact

Figure 2.40 - Right Rear Of Vehicle 511 After Impact

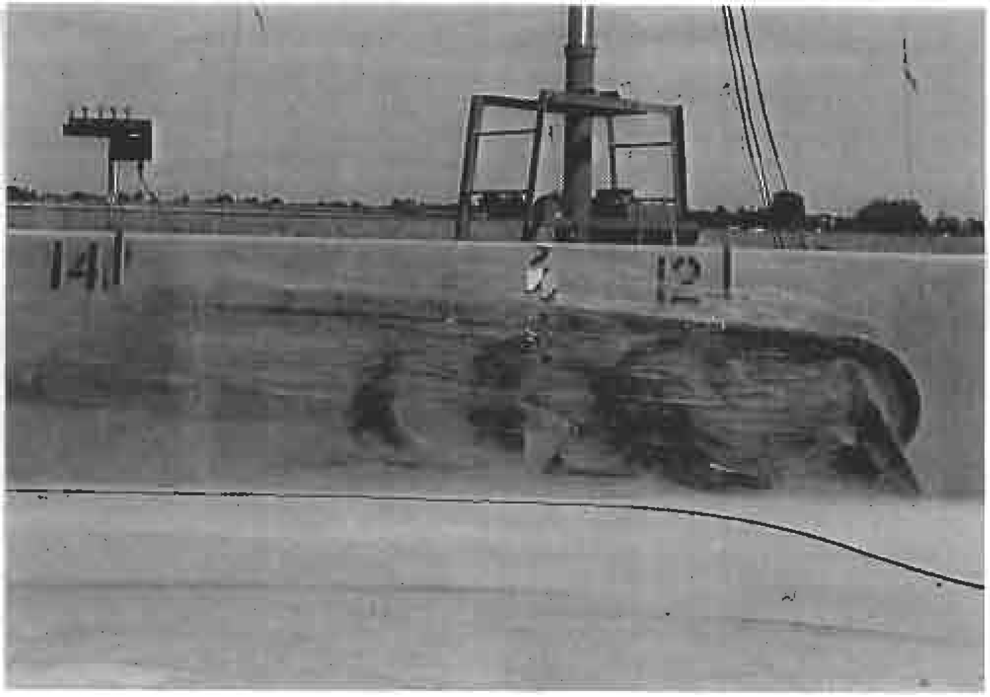
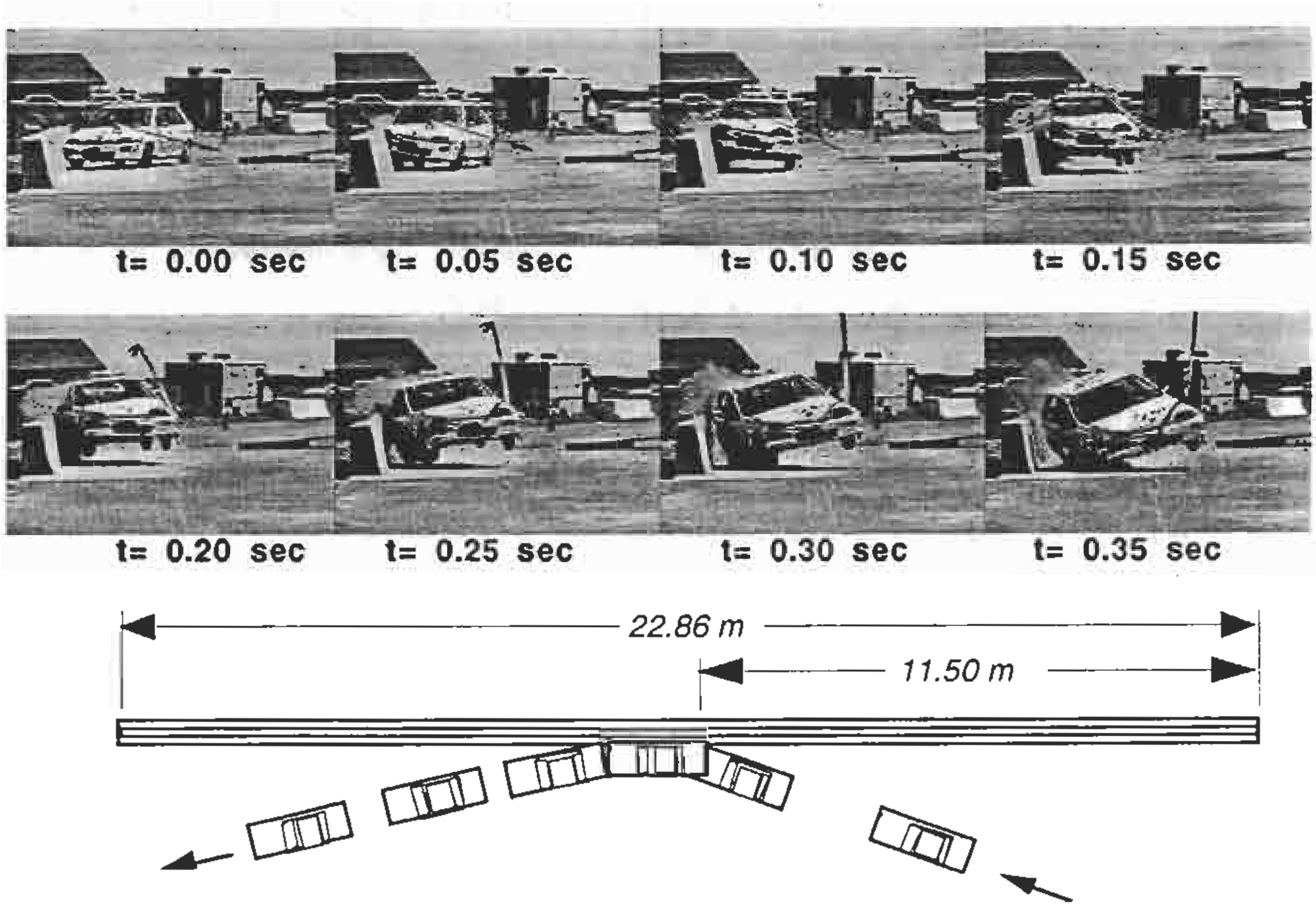


Figure 2.41 - Test 511 Impact Scuff Marks On The Type 70 Barrier

Figure 2.42 - The Down Stream View Of The Type 70 Barrier From The Resting Place Of The Test Vehicle

Figure 2.43 - Test 511 Data Summary Sheet



Test Barrier

Type:	Type 70 Bridge Rail
Length:	22.86 meters

Test Date: April 6, 1997

Test Vehicle:

Model:	1992 Geo Metro
Inertial Mass:	843 kg
Impact / Exit Velocity:	104.1 km/h / 92 km/h
Impact / Exit Angle:	20.0 / 12.1°

Test Dummy:

Type:	Hybrid III
Weight / Restraint:	74.8 kg / lap and shoulder
Position:	Front Right

Test Data:

Occ. Impact Velocity (Long / Lat):	4.51 m/s / 7.22 m/s
Ridedown Acceleration (Long / Lat):	-2.9g / -16.0g
Max. 50 ms Avg. Accel (Long / Lat):	-7.0g / -13.4g
Exterior: VDS/CDC[9]	FR-5, RD-4 / 12RFEW3
Interior: OCDI[10]	RF0000110

Barrier Damage: Only superficial scuffing

2.2.5.2. Vehicle Damage - Test 511

Damage to the vehicle was less than that reported for tests 531 and 533. The right front section of the vehicle sustained crushing of the bumper and frame, damage to the suspension and a flat tire. The hood crumpled, but did not penetrate the cab.

As the vehicle turned parallel to the barrier, the sheet metal on the entire right side came into contact with the barrier face. The rear right tire rubbed along the barrier, but was not damaged beyond moderate scuffing.

2.2.5.3. Barrier Damage - Test 511

Barrier damage was cosmetic only, consisting of scrapes and tire marks. Both of the right side tires left marks along the face of the barrier for the 6.5 meters of contact. Small amounts of concrete spalled from the face of the barrier where the vehicle's sheet metal made contact.

2.2.5.4. Dummy's Response - 511

The dummy was lap and shoulder belted. At impact, the dummy's head moved out of the passenger's side window about 100 mm. There was no contact between the dummy and the barrier face. The dummy remained upright and secure during the remainder of the test. The final resting position of dummy was upright in the passenger's seat.

2.3. Discussion of Test Results - Crash Tests

2.3.1. General - Evaluation Methods (Tests 531-534, 511)

NCHRP Report 350[2] stipulates that crash test performance be assessed according to three evaluation factors: 1) Structural Adequacy, 2) Occupant Risk, and 3) Vehicle Trajectory.

The structural adequacy, occupant risk and vehicle trajectories associated with both barriers were evaluated in comparison with Tables 3.1 and 5.1 of NCHRP 350[2].

2.3.2. Structural Adequacy

The structural adequacy of both median barriers was acceptable. There was no measurable movement in any of the barriers. During the time of contact between the test vehicles and the barriers there were negligible amounts of scraping and spalling.

A more detailed assessment summary of structural adequacy is shown in Table 2-2 through Table 2-6.

2.3.3. Occupant Risk

The occupant risk for each of the barriers is also acceptable. All of the calculated occupant ridedown accelerations and occupant impact velocities were within the “preferred” range except for tests 533 and 511, which had lateral ridedown acceleration of 16.7 g's and 16.0 g's, respectively. The preferred limit is 12 g's, but the ridedown accelerations are still less than the 20 g maximum. Therefore tests 533 and 511 are still acceptable. The minimal vehicle fragmentation and high degree of vehicle stability also minimized the occupant risk.

Please refer to Table 2-2 through Table 2-5 for a more detailed assessment summary of occupant risk

2.3.4. Vehicle Trajectory

The vehicle trajectory for each of the barriers is also acceptable. The exit angle for each test was well within the limit of 60 percent of impact angle. However, test 531 and 533 both demonstrated the same characteristic arc back into traffic. In each case the arc was very large (on the order of 50-75 m radius). The large radius turn back into traffic is not considered abrupt enough to fail the tests. Test 511 did not exhibit an arc back into traffic.

A more detailed assessment summary of vehicle trajectory may be seen in Table 2-2 through Table 2-7.

Table 2-2 - Test 531 Assessment Summary

Test No. 531
Date 2/9/95
Test agency California Dept. of Transportation

<table>
<tr><th>Evaluation Criteria</th><th>Test Results</th><th>Assessment</th></tr>
<tr><td>Structural Adequacy
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the article is acceptable</td><td>The vehicle was contained and smoothly redirected</td><td>pass</td></tr>
<tr><td>Occupant Risk
D. Detached elements, fragment or other debris from the test article should not penetrate of show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, of personnel in a work zone. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.</td><td>There was not any noticeable fragmentation of the barrier. The vehicle did not create any debris beyond that caused by the crushing of the impact.</td><td>pass</td></tr>
<tr><td>F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable</td><td>The maximum yaw, pitch and roll were 23.8, -5.3, and 5.4 degrees, respectively. All minimal.</td><td>pass</td></tr>
<tr><td>H. Occupant impact velocities (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following:<table><tr><th colspan="3">Occupant Impact Velocity Limits (m/s)</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and lateral</td><td>9</td><td>12</td></tr></table></td><td>Longitudinal Impact Vel. = 4.60 m/s
Lateral Impact Vel. = -6.83 m/s</td><td>pass</td></tr>
<tr><td>I. Occupant Ridedown Accelerations (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following:<table><tr><th colspan="3">Occupant Ridedown Acceleration Limits (G's)</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and lateral</td><td>12</td><td>20</td></tr></table></td><td>Longitudinal Acceleration. = -2.6 g's
Lateral Acceleration. = 11.3 g's</td><td>pass</td></tr>
<tr><td>Vehicle Trajectory
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes</td><td>The vehicle made a slight arc into traffic</td><td>pass marginal</td></tr>
<tr><td>M. The exit angle from the test article preferably should be less that 60 percent of the test impact angle, measured at time of vehicle loss of contact with test device."</td><td>exit angle 6.6 degrees (<11.9)</td><td>pass</td></tr>
</table>

Table 2-3 - Test 532 Assessment Summary

Test No. 532
Date 3/16/95
Test agency California Dept. of Transportation

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the article is acceptable	The vehicle was contained and redirected, but the severity of the impact did not allow for a *smooth* redirection	pass
Occupant Risk *		
D. Detached elements, fragment or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, of personnel in a work zone. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There was not any noticeable fragmentation of the barrier. The vehicle did not create any debris beyond that caused by the crushing of the impact.	pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable	The vehicle did not have excessive yaw, pitch or roll.	pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes	After impact, the vehicle turned back into the barrier	pass
L. The occupant impact velocity in the longitudinal direction should not exceed 12m/sec and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 G's.	Not available due to a failure in the data recorder.	fail
M. The exit angle from the test article preferably should be less that 60 percent of the test impact angle, measured at time of vehicle loss of contact with test device."	The exit angle was less that 60% of the impact angle	pass

* Evaluation Criteria H and I are not required for the 2000P test.

Table 2-4 - Test 533 Assessment Summary

Test No. 533

Date 6/7/95

Test agency California Dept. of Transportation

<table>
<tr><th>Evaluation Criteria</th><th>Test Results</th><th>Assessment</th></tr>
<tr><td>Structural Adequacy</td><td></td><td></td></tr>
<tr><td>A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the article is acceptable</td><td>The vehicle was contained and smoothly redirected</td><td>pass</td></tr>
<tr><td>Occupant Risk</td><td></td><td></td></tr>
<tr><td>D. Detached elements, fragment or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, of personnel in a work zone. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.</td><td>There was not any noticeable fragmentation of the barrier. The vehicle did not create any debris beyond that caused by the crushing of the impact.</td><td>pass</td></tr>
<tr><td>F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable</td><td>The maximum yaw, pitch and roll were 27.0, -10.7, and -4.6 degrees, respectively. All minimal.</td><td>pass</td></tr>
<tr><td>H. Occupant impact velocities (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following:
<table>
<tr><th colspan="3">Occupant Impact Velocity Limits (m/s)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and lateral</td><td>9</td><td>12</td></tr>
</table></td><td>Longitudinal Impact Vel. = 4.72 m/s
Lateral Impact Vel. = -7.90 m/s</td><td>pass</td></tr>
<tr><td>I. Occupant Ridedown Accelerations (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following:
<table>
<tr><th colspan="3">Occupant Ridedown Acceleration Limits (G's)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and lateral</td><td>12</td><td>20</td></tr>
</table></td><td>Longitudinal Acceleration. = -2.1 g's
Lateral Acceleration. = 16.7 g's</td><td>pass</td></tr>
<tr><td>Vehicle Trajectory</td><td></td><td></td></tr>
<tr><td>K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes</td><td>The vehicle made a slight arc into traffic</td><td>pass marginal</td></tr>
<tr><td>M. The exit angle from the test article preferably should be less that 60 percent of the test impact angle, measured at time of vehicle loss of contact with test device."</td><td>exit angle 6.5 degrees (<11.7)</td><td>pass</td></tr>
</table>

Table 2-5 - Test 534 Assessment Summary

Test No. 534
Date 11/28/95
Test agency California Dept. of Transportation

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the article is acceptable	The vehicle was contained and smoothly redirected	pass
Occupant Risk *		
D. Detached elements, fragment or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, of personnel in a work zone. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There was not any noticeable fragmentation of the barrier. The vehicle did not create any debris beyond that caused by the crushing of the impact.	pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable	The maximum yaw, pitch and roll were 31.5, 6.6, and 10.6 degrees, respectively. All minimal.	pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes	The vehicle made a slight arc into traffic	pass
L. The occupant impact velocity in the longitudinal direction should not exceed 12m/sec and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 G's.	Long. Impact Vel. = 6.80 m/s Long. Ridedown Acc. = -6.7 g's	pass
M. The exit angle from the test article preferably should be less that 60 percent of the test impact angle, measured at time of vehicle loss of contact with test device."	exit angle 6.5 degrees (<15.1)	pass

* Evaluation Criteria H and I are not required for the 2000P test.

2. TECHNICAL DISCUSSION (Continued)

Table 2-6 - Test 511 Assessment Summary

Test No. 511

Date 5/6/97

Test agency California Dept. of Transportation

<table>
<tr><th>Evaluation Criteria</th><th>Test Results</th><th>Assessment</th></tr>
<tr><td>Structural Adequacy
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the article is acceptable</td><td>The vehicle was contained and smoothly redirected</td><td>pass</td></tr>
<tr><td>Occupant Risk
D. Detached elements, fragment or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, of personnel in a work zone. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.</td><td>There was not any noticeable fragmentation of the barrier. The vehicle did not create any debris beyond that caused by the crushing of the impact.</td><td>pass</td></tr>
<tr><td>F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable</td><td>The maximum yaw, pitch and roll were -28.2, 3.6, and 12.7 degrees, respectively. All minimal.</td><td>pass</td></tr>
<tr><td>H. Occupant impact velocities (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following:
<table>
<tr><th colspan="3">Occupant Impact Velocity Limits (m/s)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and lateral</td><td>9</td><td>12</td></tr>
</table></td><td>Longitudinal Impact Vel. = 4.51 m/s
Lateral Impact Vel. = 7.22 m/s</td><td>pass</td></tr>
<tr><td>I. Occupant Ridedown Accelerations (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following:
<table>
<tr><th colspan="3">Occupant Ridedown Acceleration Limits (G's)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and lateral</td><td>12</td><td>20</td></tr>
</table></td><td>Longitudinal Acceleration. = -2.9 g's
Lateral Acceleration. = -16. g's</td><td>pass</td></tr>
<tr><td>Vehicle Trajectory
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes</td><td>The vehicle maintained a relatively straight course after exiting the barrier</td><td>pass</td></tr>
<tr><td>M. The exit angle from the test article preferably should be less that 60 percent of the test impact angle, measured at time of vehicle loss of contact with test device."</td><td>exit angle 12.1 degrees (~12)</td><td>pass</td></tr>
</table>

Table 2-7 - Vehicle Trajectories and Speeds

Test Number	Impact Angle (deg)	60% of Impact Angle (deg)	Exit Angle (deg)	Impact Speed, V_i (km/h)	Exit Speed, V_e (km/h)	Speed Change $V_i - V_e$ (km/h)
531	19.8	11.9	6.6	91.8	83.0	8.8
532*	53.0	31.8	2.0	71.5	33.0	38.5
533	19.5	11.7	6.5	92.9	79.4	13.5
534	25.2	15.1	6.5	97.7	83.1	14.6
511	20.0	12.0	12.1	104.1	92.0	12.1

* Test 532 impacted at a speed and angle different than initially planned due to a failure of the guidance system. The test results are included in this report because this test is intended to measure structural adequacy of the barrier and the impact conditions partially fulfill this intent.

3. CONCLUSION

Based on the construction and testing of the single slope barriers discussed in this report the following conclusions can be drawn:

1. A 1420 mm high barrier with a 9.1 degree slope can be successfully slip-formed over AC pavement.

2. The Type 60G barrier can successfully contain a 2000 kg pickup truck impacting at ~~20~~ 25 degrees and 100 km/hr.

3. Both the Texas barrier and the Type 60G barrier can smoothly redirect a small car and a pickup without any significant adverse consequences beyond damage to the impacting wheel assembly.

4. Since none of the vehicles rose more than 250 mm off the ground, an 820 mm or higher Type 60 barrier should perform as well as the 1420 mm high Type 60G.

4. RECOMMENDATIONS

1. The Type 60 barrier is recommended as a replacement for the Type 50 barrier.

2. The Type 60G barrier is recommended for use on state highways where a concrete median barrier with glarescreen is required.

3. Where a concrete barrier without a glarescreen is required, the 910 mm high Type 60 barrier is recommended.

4. Where an adequate stopping sight distance cannot be achieved with a 910 mm barrier, an 820 mm Type 60 barrier is recommended.

5. IMPLEMENTATION

The Office of Structures Design will be responsible for the preparation of standard plans and specifications for the Type 60 barrier, with technical support from the Office of Materials Engineering and Testing Services and the Traffic Operations Program. Similarly, the Office of Structures Design, with assistance from the Office of Materials Engineering and Testing Services and the Traffic Operations Program, will be responsible for the in-service evaluation.

6. REFERENCES

1. "Roadside Design Guide", American Association of State Highway and Transportation Officials, 1988.

2. "Recommended Procedures for the Safety Performance Evaluation of Highway Features", Transportation Research Board, National Cooperative Highway Research Program Report 350, 1993.

3. Seamons, L. L. and Smith, R. N., "Past and Current Median Barrier Practice in California", California Department of Transportation, June 1991.

4. Bronstad, M. E., et. al., "Concrete Median Barrier Research - Volume I, Executive Summary", Federal Highway Administration, Report No. FHWA-RD-77-3, June 1976.

5. "Single-Slope Concrete Median Barrier", Transportation Research Record 1302, Transportation Research Board, 1991.

6. "Development of a Single-Slope Concrete Median Barrier", W. Lynn Beason et. al., Texas Transportation Institute, Report No. 9429 CDK-1.

7. "Glare Screen Guidelines", National Cooperative Highway Research Program Synthesis of Highway Practice 66, December 1979.

8. "Standard Specifications", California Department of Transportation, Sacramento, Ca., 1989.

9. "Vehicle Damage Scale for Traffic Accident Investigators", Traffic Accident Data Project, National Safety Council, 1968.

10 "Collision Deformation Classification" - SAE J224 Mar80, SAE Recommended Practices, 1980.

7. APPENDICES

7.1. Test Vehicle Equipment

The test vehicles were modified as follows for the crash tests:

- The gas tanks on the test vehicles were disconnected from the fuel supply line and drained. A one-gallon safety gas tank was installed in the trunk compartment (or truck bed) and connected to the fuel supply line. On 2000 kg pickups, the gas tank was filled with water prior to the test. In 820 kg cars the gas tanks were removed.

- Two pairs of 12-volt wet cell motorcycle storage batteries were mounted in the vehicle. The first pair of batteries operated the solenoid-valve braking system and other test equipment in the vehicle. The second pair of batteries powered the TDR data acquisition system.

- The gas pedal was linked to a small cylinder with a piston which opened the throttle. The piston was activated when a hand-thrown switch on the rear fender of the test vehicle opened a valve and pressurized a CO_2 tube leading to the cylinder and piston. The cylinder was connected to the same CO_2 tube used for the brake system, but a separate regulator controlled the pressure.

- A speed control device, connected between the negative side of the coil and the vehicle battery, regulated the speed of the test vehicle based on speedometer cable output. This device was calibrated prior to the test by conducting a series of trial runs through a speed trap composed of two tape switches set a specified distance apart and connected to a digital timer.

- A microswitch was mounted below the front bumper and connected to the ignition system. A trip plate on the ground near impact triggered the switch when the car passed over it, thus opening the ignition circuit and shutting off the vehicle engine immediately before impact.

- A solenoid valve-actuated CO_2 system controlled remote braking after impact and emergency braking any other time. Part of this system was a cylinder with a piston which was attached to the brake pedal. The pressure operating the piston was set during trial runs to stop the test vehicle without locking the wheels. When activated, the brakes could be applied in less than 100 milliseconds.

- The remote brakes were controlled at a console trailer. A cable ran from the console trailer to an electronic instrumentation trailer. From there, the remote brake signal was carried on one channel of a tether line which was connected to the test vehicle. Any loss of continuity in these cables would have activated the brakes and cut off the ignition automatically. Also, when the brakes were applied by remote control from the console trailer, the ignition was automatically cut.

Table 7-1 - Test 531 Vehicle Dimensions

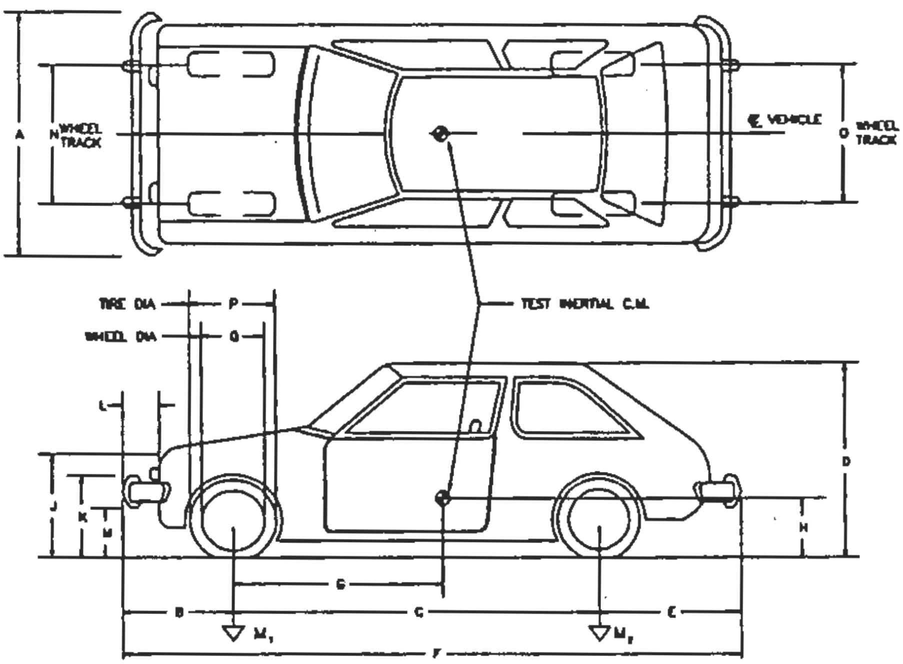
DATE: 2/9/95 TEST NO: T531 VIN NO: IT2EL33F6LO517833 MAKE: TOYOTA

MODEL: TERCEL YEAR: 1990 ODOMETER: 066617 TIRE SIZE: 155R13

TIRE INFLATION PRESSURE: 44 (PSI)

MASS DISTRIBUTION (kg) LF 296 RF 288 LR 184 RR 173

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST: THE DRIVERS SIDE HAD A SMALL DENT JUST BEHIND THE DOOR. THE FRONT GRILL WAS LOOSE.



ENGINE TYPE: 4 CYL E.F.I.

ENGINE CID: 1.5 LITER

TRANSMISSION TYPE :

X AUTO

MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: HYBRID II 50th %

MASS: 75kg

SEAT POSITION: LEFT FRONT

GEOMETRY (cm)

A 164	D 135	G 104	K 49.5	N 140	Q 35.6
B 79	E 100	H 36	L 10	O 139	
C 240	F 418	J 68.5	M 38	P 56	

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M1	546	584	620
M2	267	357	396
M3	813	941	1016

Table 7-2 - Test 532 Vehicle Dimensions

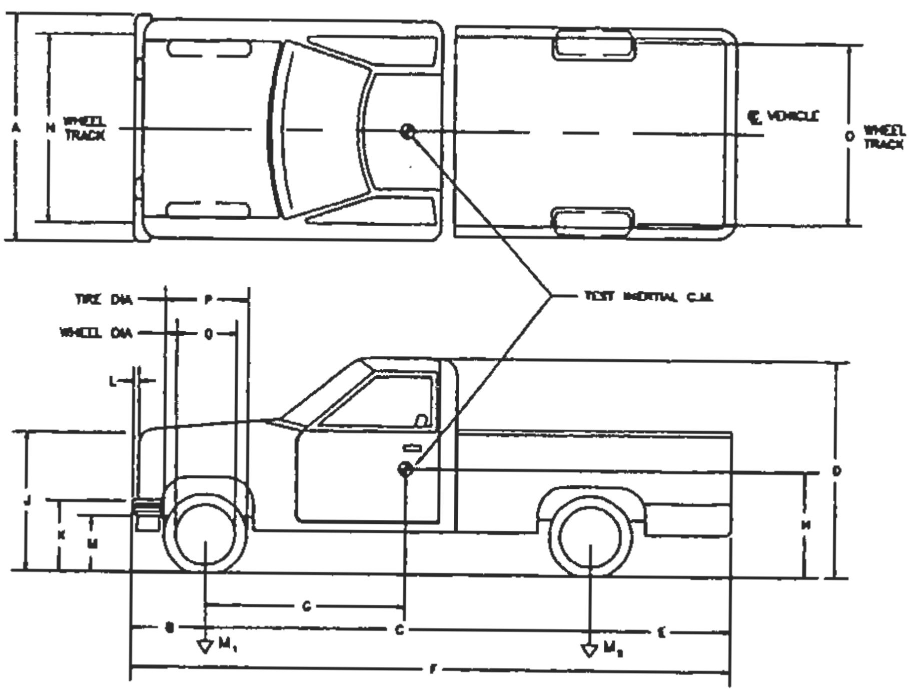
DATE: 3/16/95 TEST NO: T532 VIN NO: 1GCGC24K5LE100888 MAKE: CHEVY

MODEL: CHEYENNE YEAR: 1989 ODOMETER: 16216 TIRE SIZE: 245/75R16

TIRE INFLATION PRESSURE: 80 (PSI)

MASS DISTRIBUTION (kg) LF 546 RF 564 LR 433 RR 417

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE:

ENGINE CID: 5.7 LITER

TRANSMISSION TYPE :

X AUTO

MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: NONE

MASS: —

SEAT POSITION:

GEOMETRY (cm)

A 183	D 182	G 142	K 66	N 183	Q 42
B 68.6	E 348	H 77.5	L 11.4	O	
C 338	F 559	J 106.7	M 43.2	P 75	

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M1	1008	1110	1110
M2	768	850	850
M3	1776	1960	1960

Table 7-3 - Test 533 Vehicle Dimensions

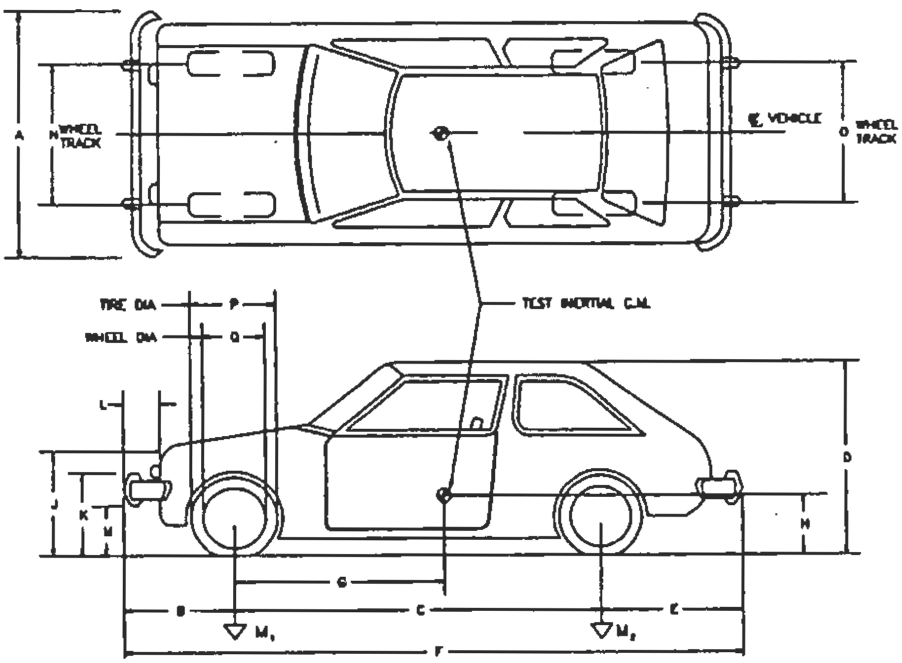
DATE: 5/30/95 TEST NO: T533 VIN NO: JTZEL33M6L0528295 MAKE: TOYOTA

MODEL: TERCEL YEAR: 1990 ODOMETER: 77328 TIRE SIZE: 155R13

TIRE INFLATION PRESSURE: 44 (PSI)

MASS DISTRIBUTION (kg) LF 303 RF 305 LR 163 RR 152.5

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST: NONE



ENGINE TYPE: 4 CYL. E.F.I.

ENGINE CID: 1.5 LITER

TRANSMISSION TYPE :

X AUTO

___ MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: HYBRID II 50th %

MASS: 75 KG

SEAT POSITION: LEFT FRONT

GEOMETRY (cm)

A 161.3	D 139.4	G	K 50.5	N 138.4	Q 36.2
B 85.10	E 67.9	H 40.60	L 9.21	O 138.4	
C 237.2	F 385.4	J 69.22	M 38.1	P 56.5	

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M1	570	608	644
M2	225	315	654
M3	795	923	998

Table 7-4 - Test 534 Vehicle Dimensions

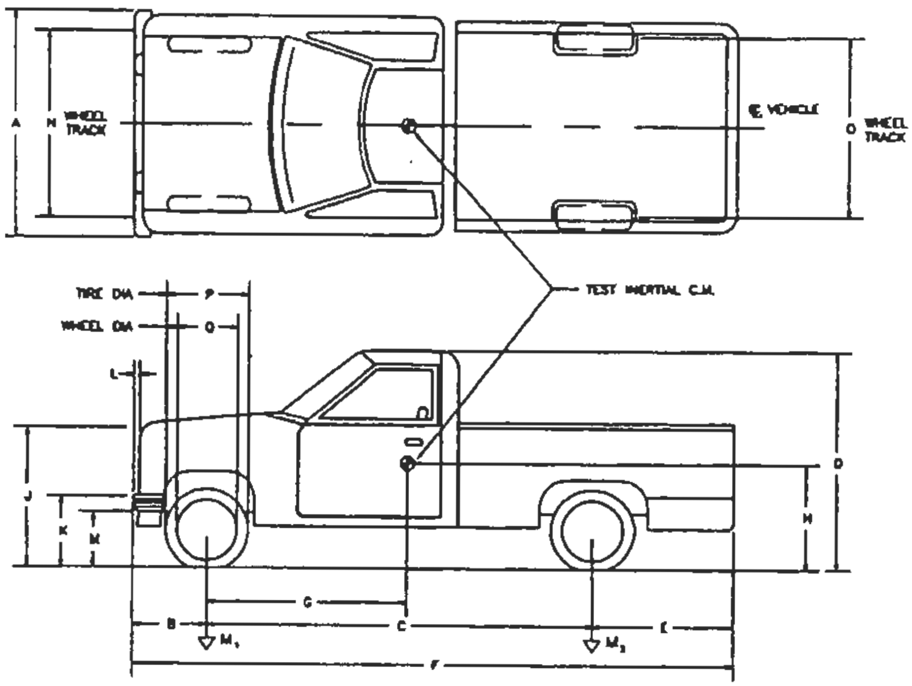
DATE: 3/27/95 TEST NO: 534 VIN NO: 1GCGC24KXKE12299 MAKE: CHEVY

MODEL: SIVERADO YEAR: 1989 ODOMETER: 018241 TIRE SIZE: LT 245/75R16

TIRE INFLATION PRESSURE: 80 (PSI)

MASS DISTRIBUTION (kg) LF 572 RF 575 LR 421 RR 431

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE:

ENGINE CID: 5.7 LITER

TRANSMISSION TYPE :

X AUTO

MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: NONE

MASS:

SEAT POSITION:

GEOMETRY (cm)

A 188	D 182.9	G 142	K 66	N 160	Q 44.5
B 87.6	E 135	H 77.5	L 11.4	O 160	
C 335.3	F 552.5	J 111.8	M 44.5	P 73.7	

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M1	1121	1147	1147
M2	750	852	852
M3	1871	1999	1999

Table 7-5 - Test 511 Vehicle Dimensions

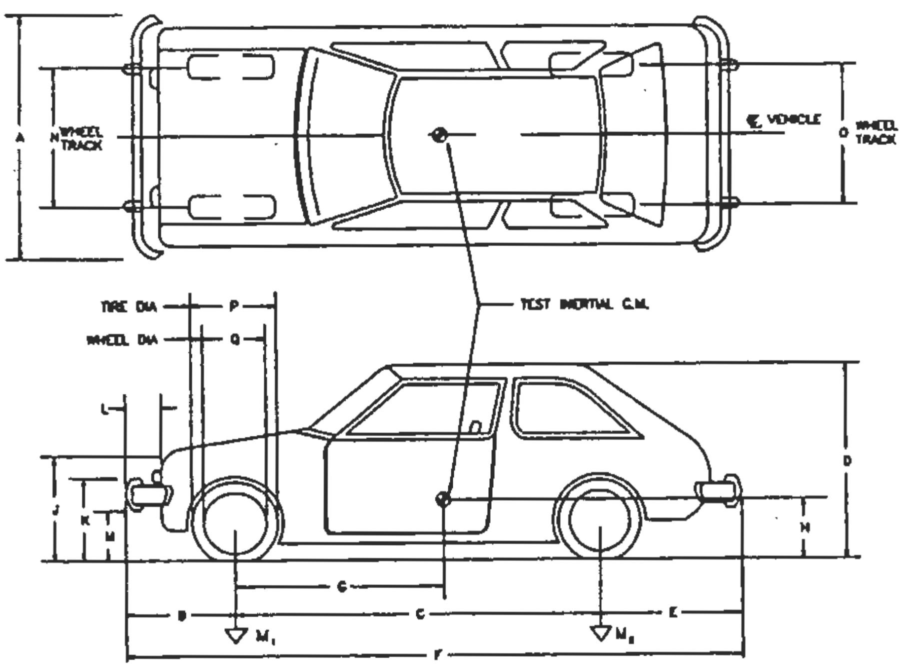
DATE: 5/6/95 TEST NO: T511 VIN NO: 2CIMR6467N6743016 MAKE: GEO

MODEL: METRO YEAR: 1992 ODOMETER: 57560 (MI) TIRE SIZE: 155R1276S

TIRE INFLATION PRESSURE: 44 (PSI)

MASS DISTRIBUTION (kg) LF 257 RF 246 LR 169 RR 170

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST: 250 mm CRACK IN WINDSHIELD



ENGINE TYPE: 3 CYL.

ENGINE CID: 1.5 LITER

TRANSMISSION TYPE :

X AUTO

____ MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: HYBRID II 50th %

MASS: 75 KG

SEAT POSITION: RIGHT FRONT

GEOMETRY (cm)

A 151.1	D 139.7	G 143.0	K 51.2	N 134.6	Q 33.0
B 196.9	E 71.2	H 27.9	L 10.2	O 132.2	
C 236.5	F 322.5	J 71.2	M 24.2	P 53.3	

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M1	485	503	553
M2	327	340	367
M3	812	843	920

7.2. Test Vehicle Guidance System

A rail guidance system directed the vehicle into the barrier. The guidance rail, anchored at 6.1 m intervals along its path, was used to guide a mechanical arm which was attached to the front left wheel of the vehicle. A rope was used to trigger the release mechanism on the guidance arm, thereby releasing the vehicle from the mechanical guidance before impact.

7.3. Photo - Instrumentation

Several high-speed movie cameras recorded the impact during the crash tests. The types of cameras and their locations are shown in Figure 7.1 and Table 7-6

All of these cameras were mounted on tripods except three cameras that were mounted on a 10.7 m high tower directly over the point of impact on the test barrier.

These cameras were connected by cables to a console trailer near the impact area which contained eight 12-volt batteries. Most of the cameras were turned on remotely from a control panel on the trailer. Other cameras were turned on by hand. The test vehicle and test barrier were photographed before and after impact with a normal speed movie camera, a black and white still camera and a color still camera. A film report of this project has been assembled using edited portions of the crash testing coverage.

Figure 7.1 - Camera Layout

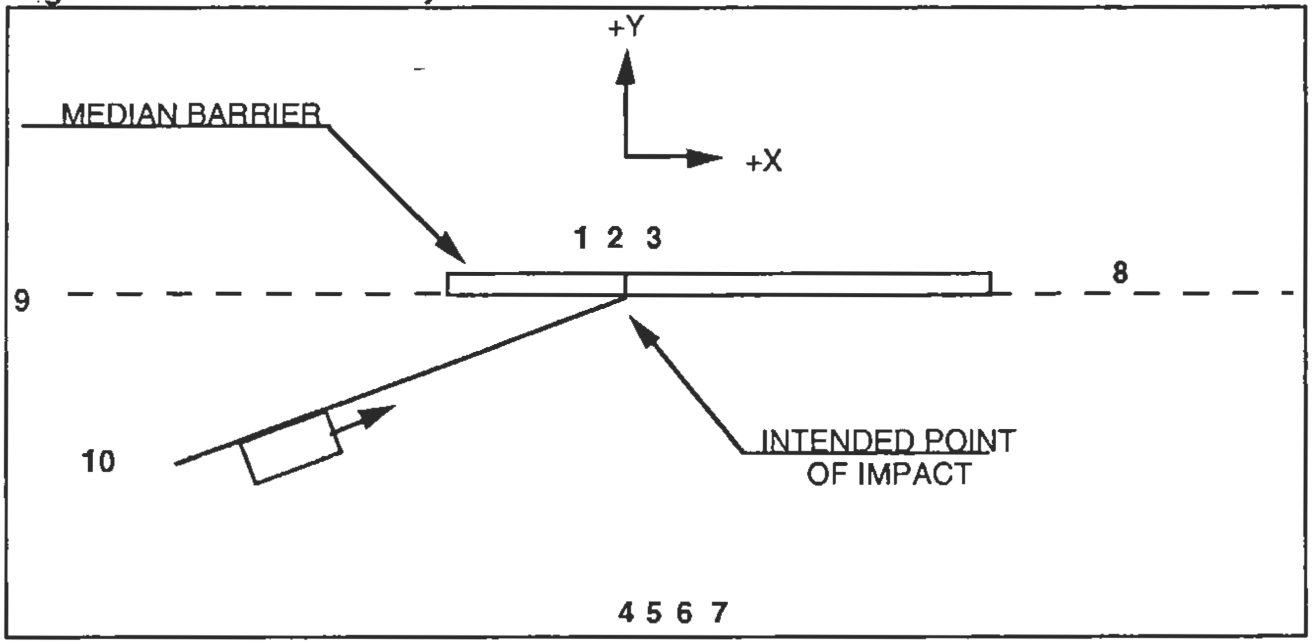


Table 7-6 - Typical Camera Locations

Typical Coordinates, m					
Cam. No.	Film mm	Camera Type	Rate: fr./sec.	Test 532	
				X	Y
1	16	PHOTOSONIC #4	400	-0.5	0
2	16	PHOTOSONIC #5	400	0	0
3	16	PHOTOSONIC #6	400	0.5	0
4	16	LOCAM 1	400	0.0	-26.0
5	16	GISMO	64	0.0	-26.0
6	16	SONY VIDEO	--	0.0	-26.0
7	16	HULCHER 35	20	0.0	-26.0
8	16	LOCAM 2	400	55.0	0.0
9	16	LOCAM 3	400	-36.5	0.0
10	35	LOCAM 4	400	76.0	-35.5

Note: Camera location measurements were approximated and are typical for all crash tests involved in this report.

The following are the pretest procedures that were required to enable film data reduction on a film motion analyzer:

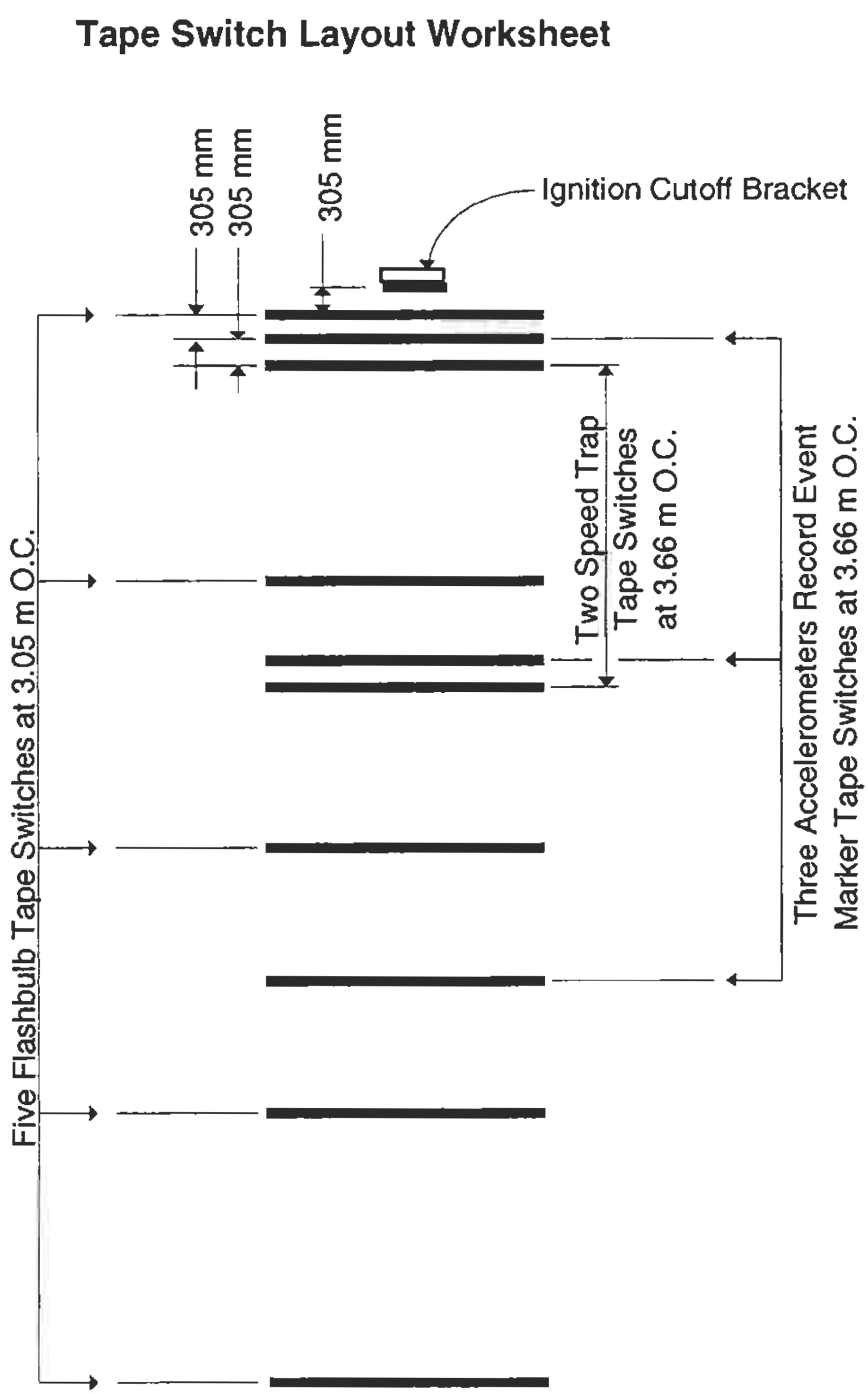
1) Butterfly targets were attached to the top and sides of the test vehicles. The targets were located at 1, 2, or 4 ft. intervals on the vehicles. The targets established scale factors and horizontal and vertical alignment. The test barrier was targeted with black and white tape.

2) Flashbulbs, mounted on the test vehicle, were electronically flashed to establish (a) initial vehicle to barrier contact, and (b) the application of the vehicle brakes. The impact flashbulbs have a delay of several milliseconds before lighting up.

3) Five tape switches, placed at 3.05 m intervals, were attached to the ground perpendicular to the path of the impacting vehicle near the barrier. Flash bulbs were activated sequentially when the tires of the test vehicle rolled over the tape switches. The flashbulb stand was placed in view of most of the data cameras. The flashing bulbs were used to correlate the cameras with the impact events and to calculate the impact speed independent of the electronic speed trap. The tape switch layout is shown in Figure 7.2.

4) Critical high-speed cameras had timing light generators which exposed red timing pips on the film at a rate of 1000 (or 100) per second. The pips were used to determine camera frame rates and to establish time-sequence relationships.

Figure 7.2 - Tape Switch Layout



7.4. *Electronic Instrumentation and Data*

The accelerometer data were also recorded on a Pacific Instruments digital transient data recorder (TDR) which was mounted in the vehicle. The TDR data were reduced using a microcomputer.

Three pressure-activated tape switches were placed on the ground in front of the test barrier. They were spaced at carefully measured intervals of 3.66 m. When the test vehicle tires passed over them, the switches produced sequential impulses or "event blips" which were recorded concurrently with the accelerometer signals on the TDR, serving as "event markers". A tape switch on the front bumper of the vehicle closed at the instant of impact and activated flash bulbs mounted on the vehicle. The closure of the bumper switch also put a "blip" or "event marker" on the TDR. A time cycle was recorded continuously on the TDR with a frequency of 500 cycles per second. The impact velocity of the vehicle could be determined from the tape switch impulses and timing cycles. Two other tape switches connected to a speed trap were placed 3.66 m apart just upstream of the test barrier specifically to establish the impact speed of the test vehicle. The tape switch layouts are shown in Figure 7.2.

The data curves are shown in Figure 7.4 through Figure 7.22 and include the accelerometer and rate gyro records from the test vehicles. They also show the longitudinal velocity and displacement versus time. These plots were needed to calculate the occupant impact velocity defined in Reference 2. All curves were calculated using software written by Pacific Instruments and modified by Caltrans.

Table 7-7 - Accelerometer Specifications

TYPE	LOCATION	RANGE	ORIENTATION	TEST NUMBER
STATHAM	VEHICLE C.G.	100 G	LONGITUDINAL	ALL
STATHAM	VEHICLE C.G.	100 G	LATERAL	ALL
STATHAM	VEHICLE C.G.	50 G	VERTICAL	ALL
HUMPHREY	VEHICLE C.G.	180 DEG/SEC	ROLL	ALL
HUMPHREY	VEHICLE C.G.	90 DEG/SEC	PITCH	ALL
HUMPHREY	VEHICLE C.G.	180 DEG/SEC	YAW	ALL
ENDEVCO	VEHICLE C.G.	200 G	LONGITUDINAL	ALL
ENDEVCO	VEHICLE C.G.	200 G	LATERAL	ALL
ENDEVCO	VEHICLE C.G.	200 G	VERTICAL	ALL

Figure 7.3 - Vehicle Accelerometer Sign Convention

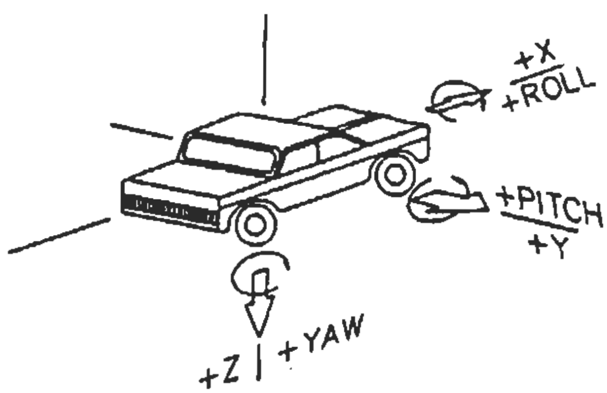


Figure 7.4 - Test 531 Vehicle Accelerations-Vs-Time

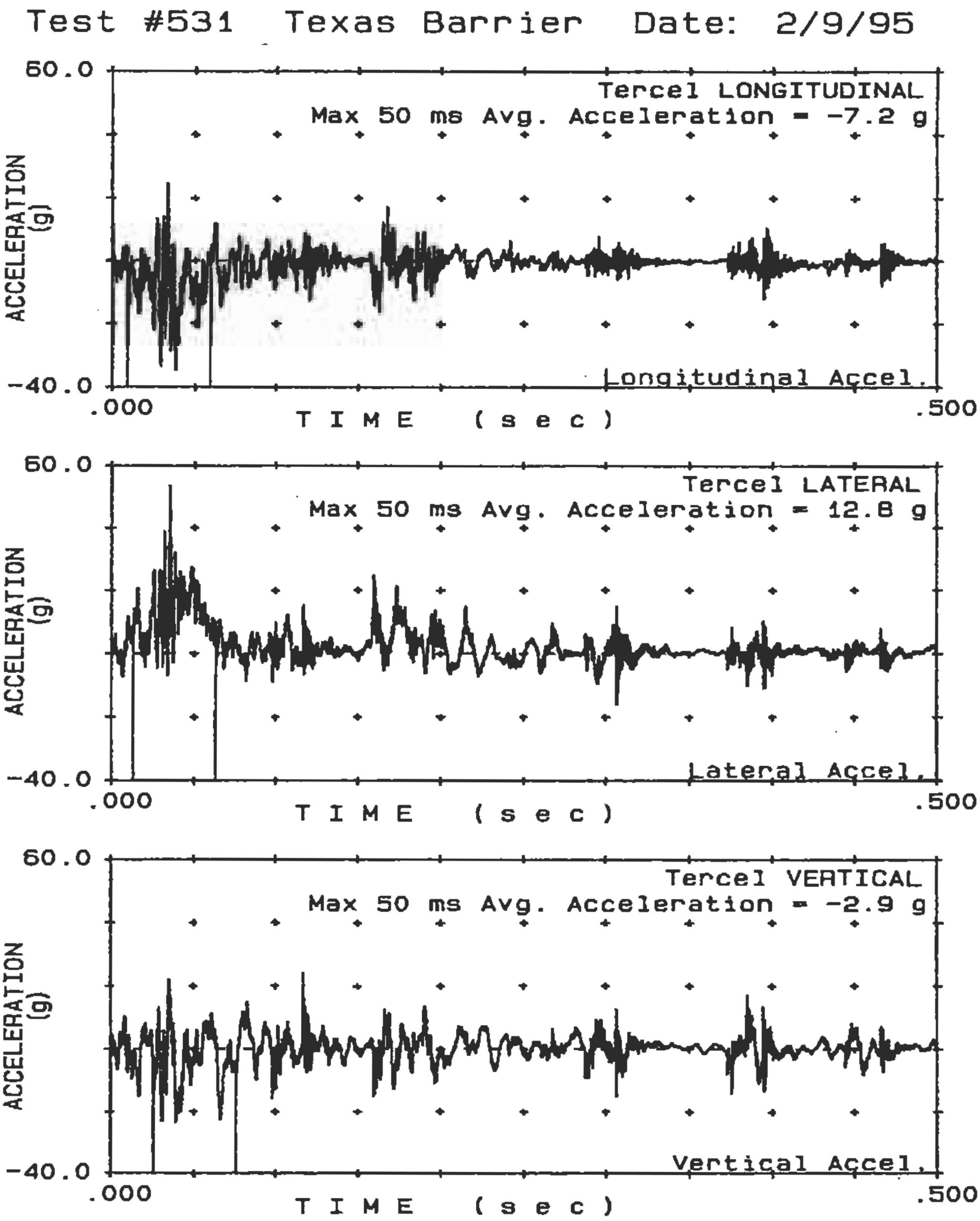


Figure 7.5 - Test 531 Vehicle Longitudinal Acceleration, Velocity and Distance -vs- Time

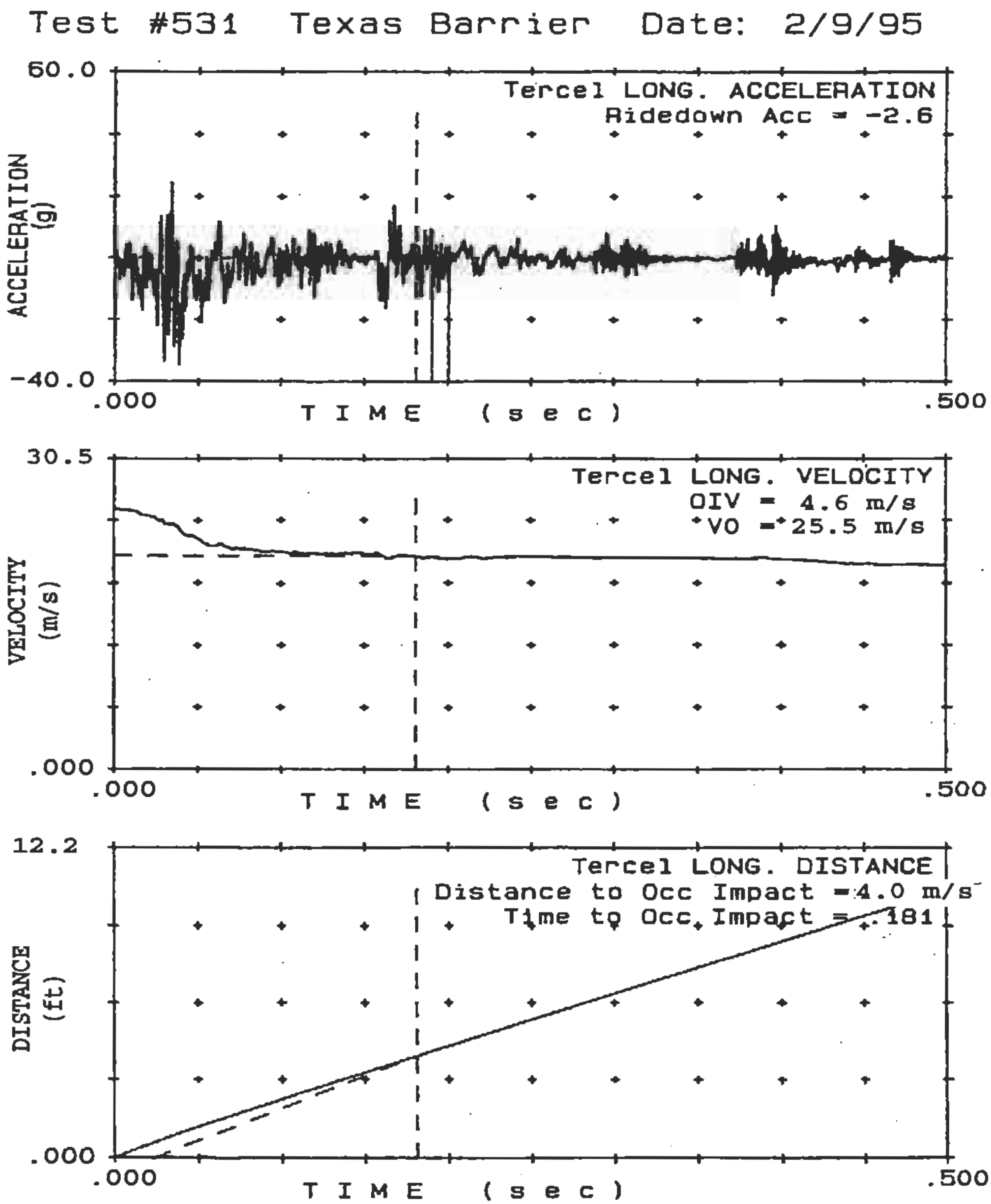


Figure 7.6 - Test 531 Vehicle Lateral Acceleration, Velocity and Distance -vs- Time

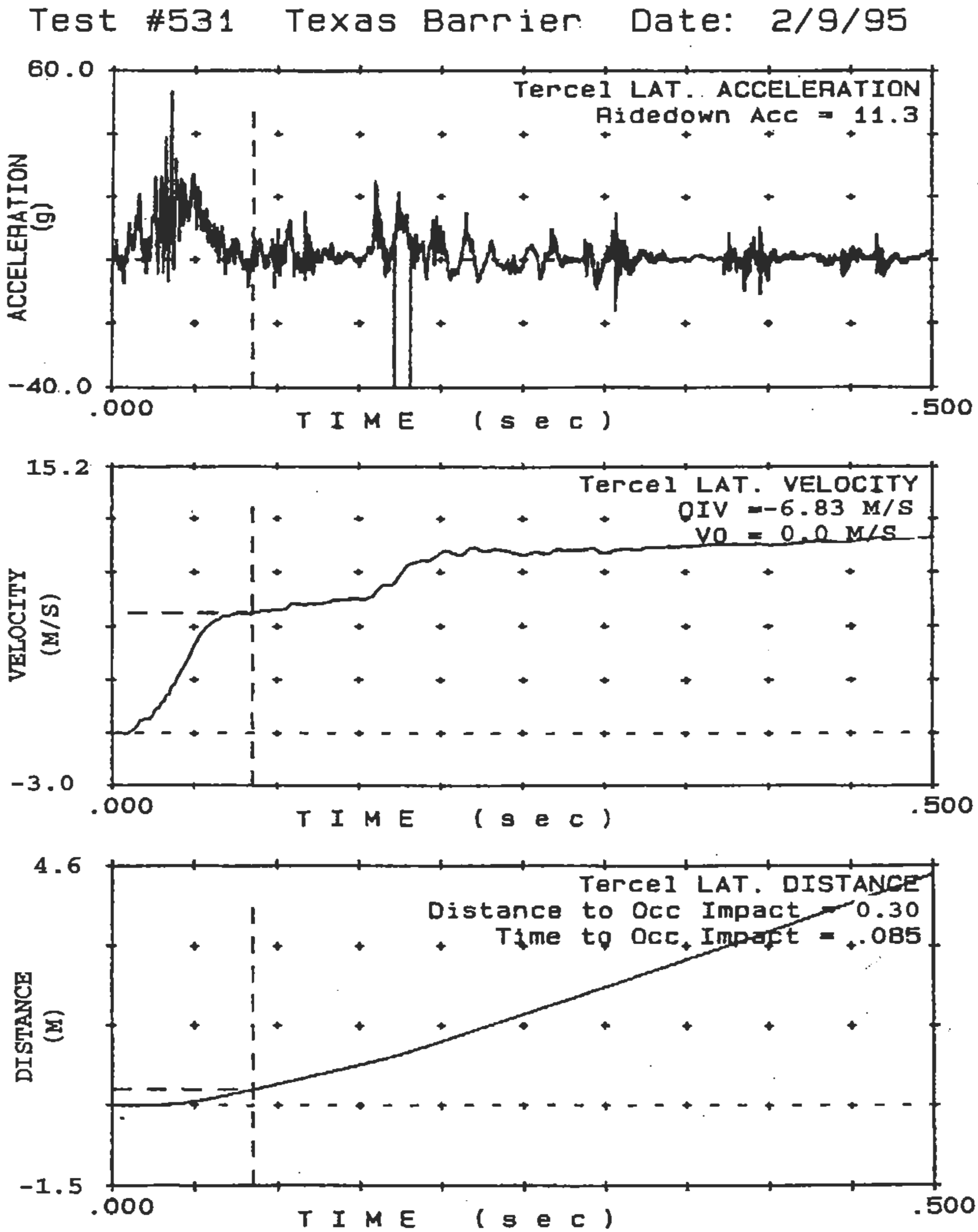


Figure 7.7 - Test 531 Vehicle Roll, Pitch, and Yaw -vs- Time

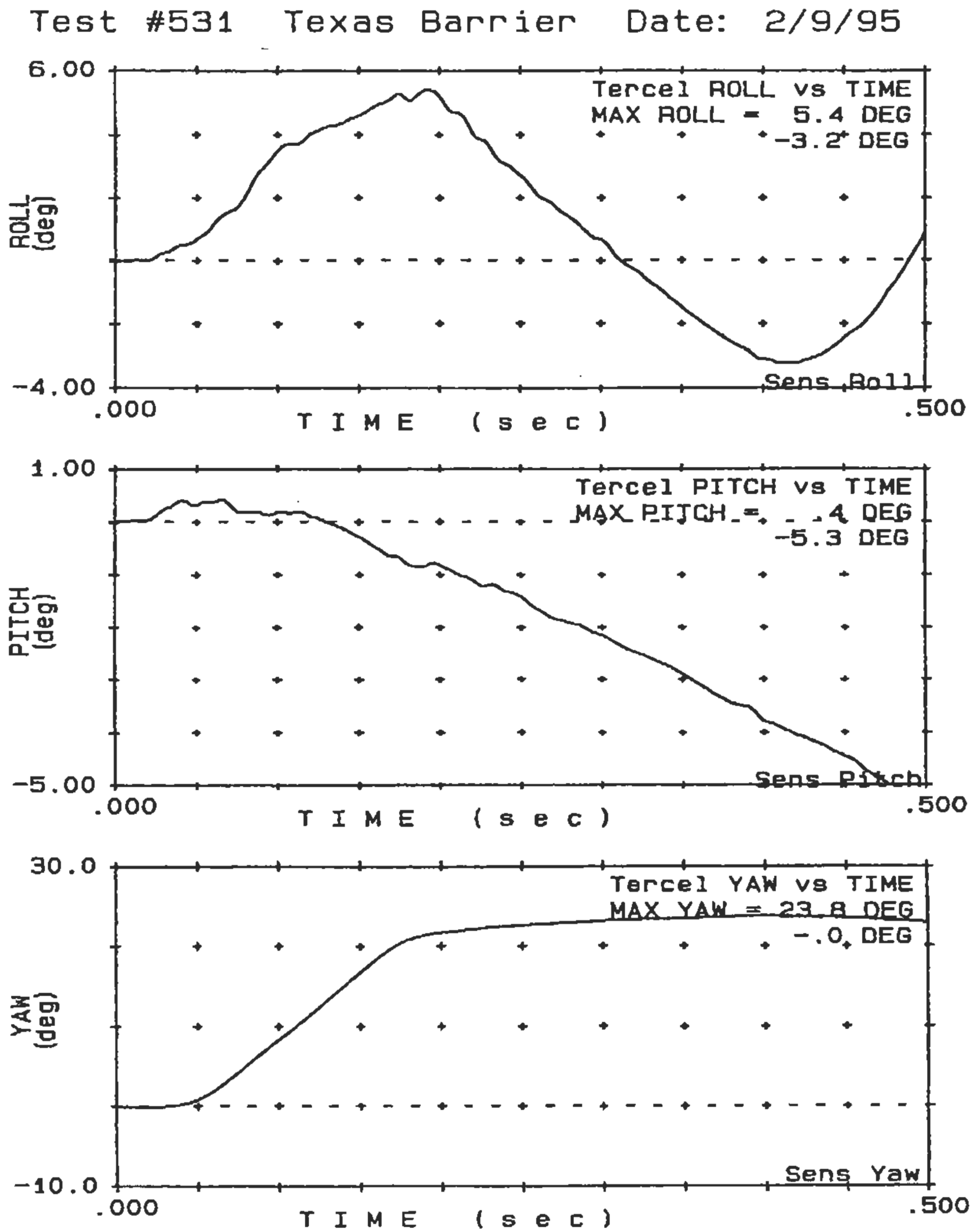


Figure 7.8 - Test 531 Dummy Head Accelerations -vs- Time

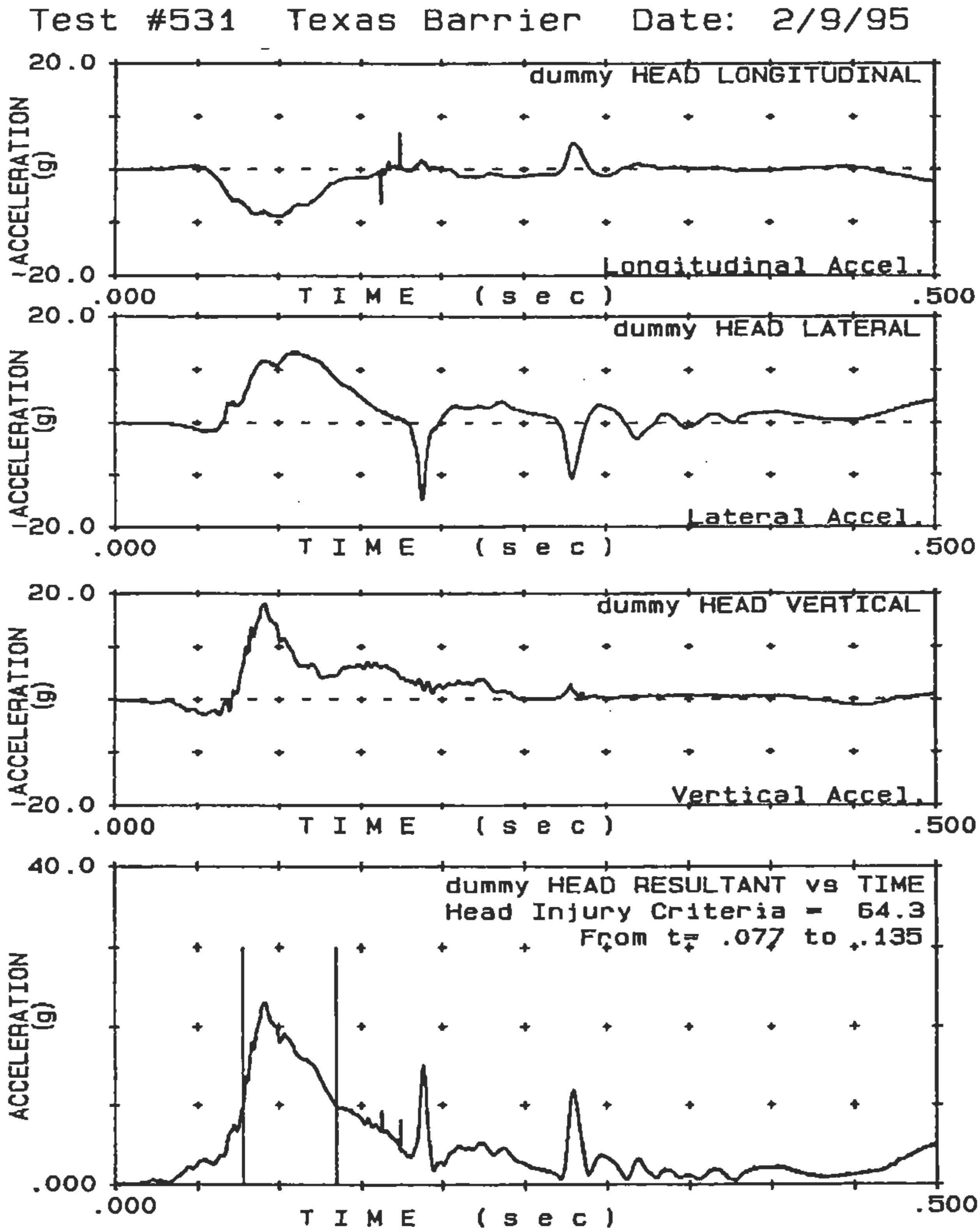


Figure 7.9 - Test 533 Vehicle Accelerations -vs- Time

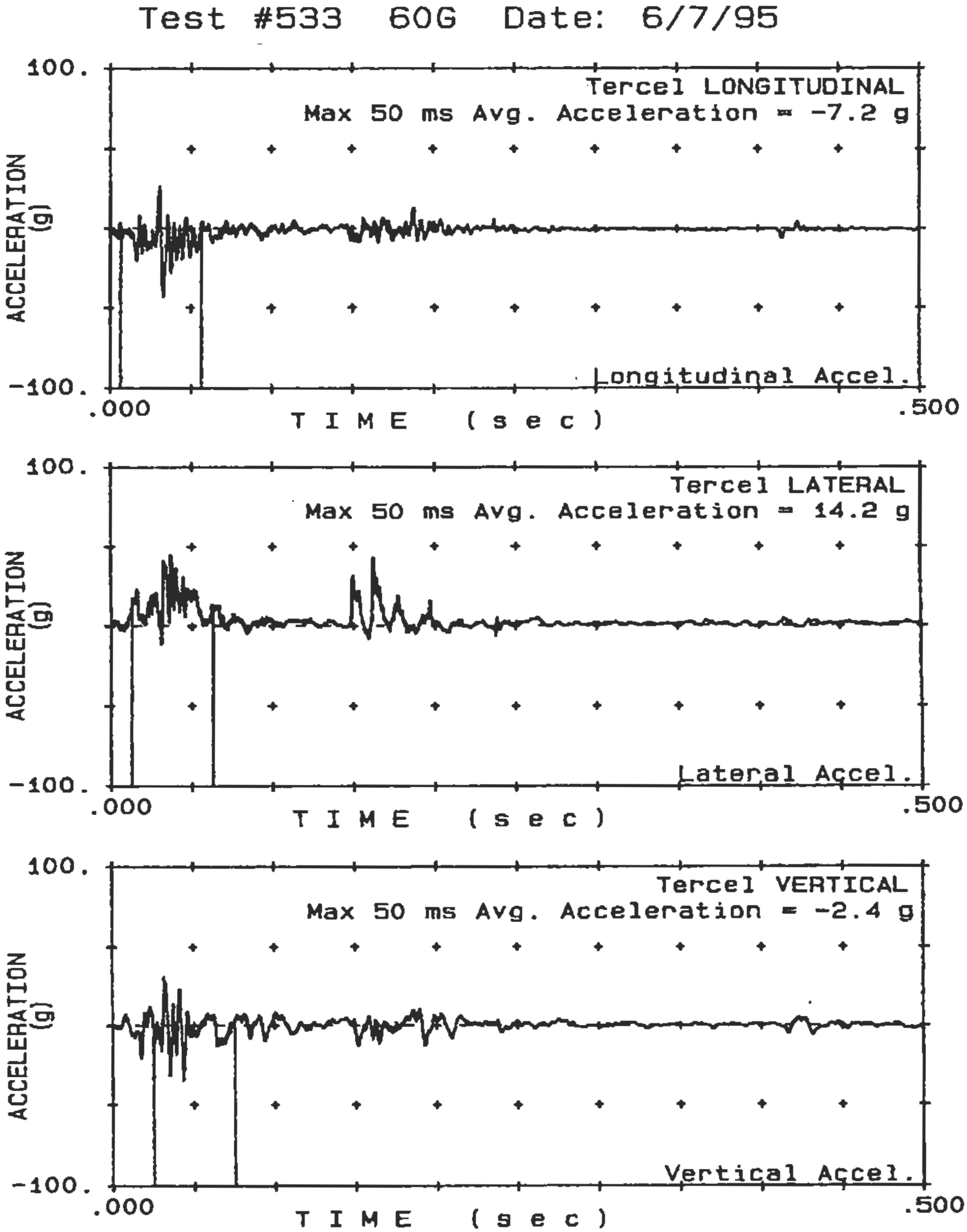


Figure 7.10 - Test 533 Vehicle Longitudinal Acceleration, Velocity, and Distance -vs- Time

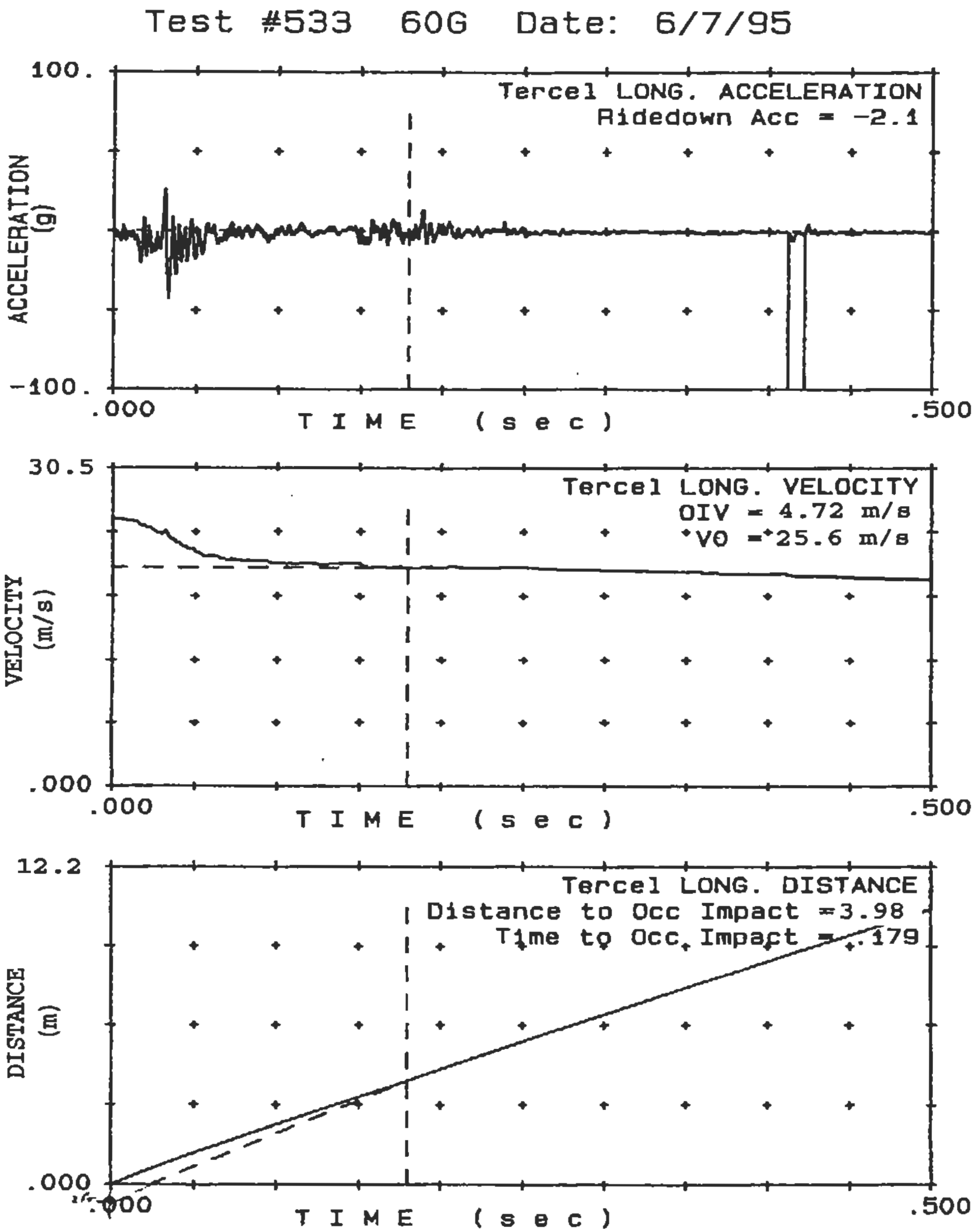


Figure 7.11 - Test 533 Vehicle Lateral Acceleration, Velocity, and Distance -vs- Time

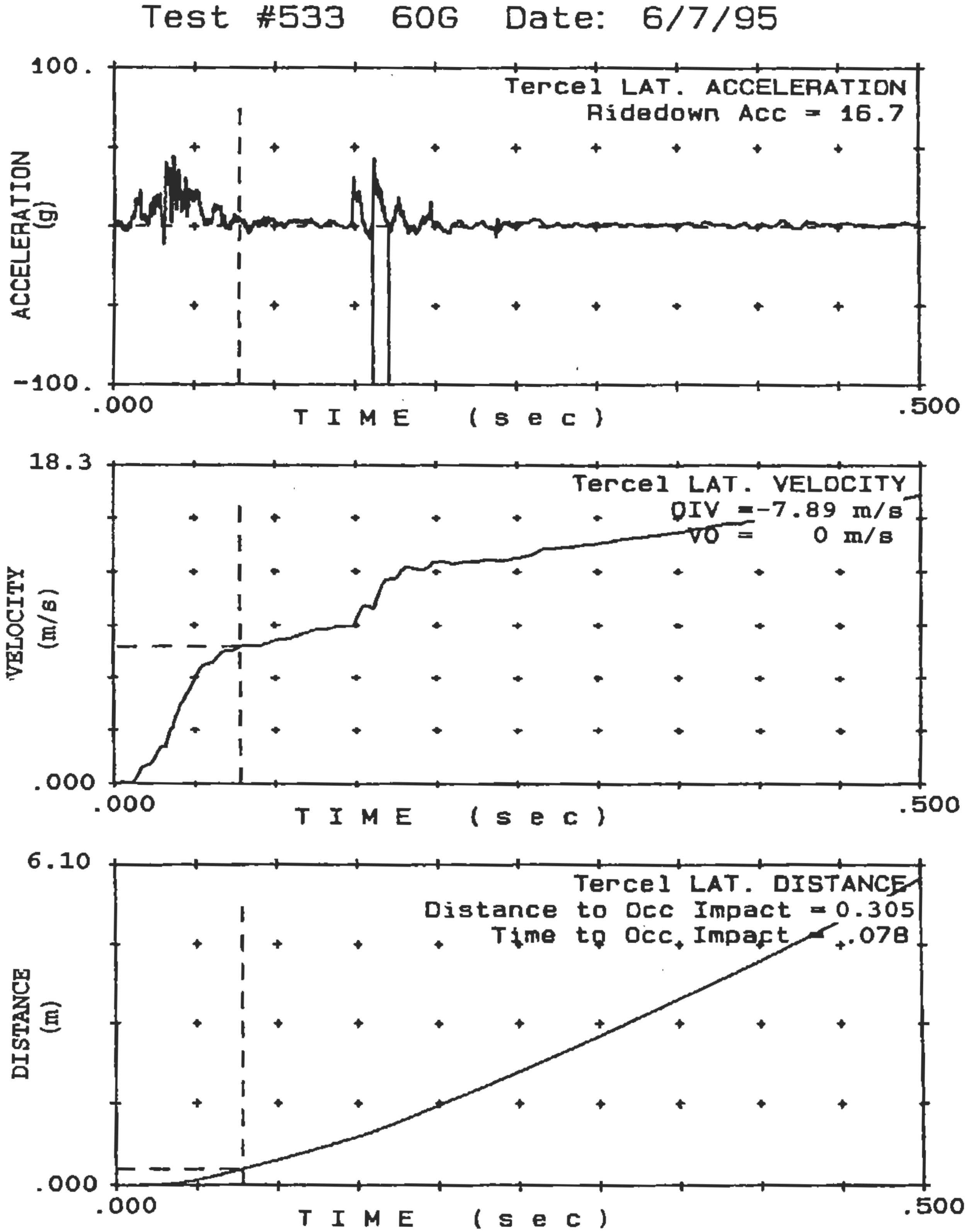


Figure 7.12 - Test 533 Vehicle Roll, Pitch and Yaw -vs- Time

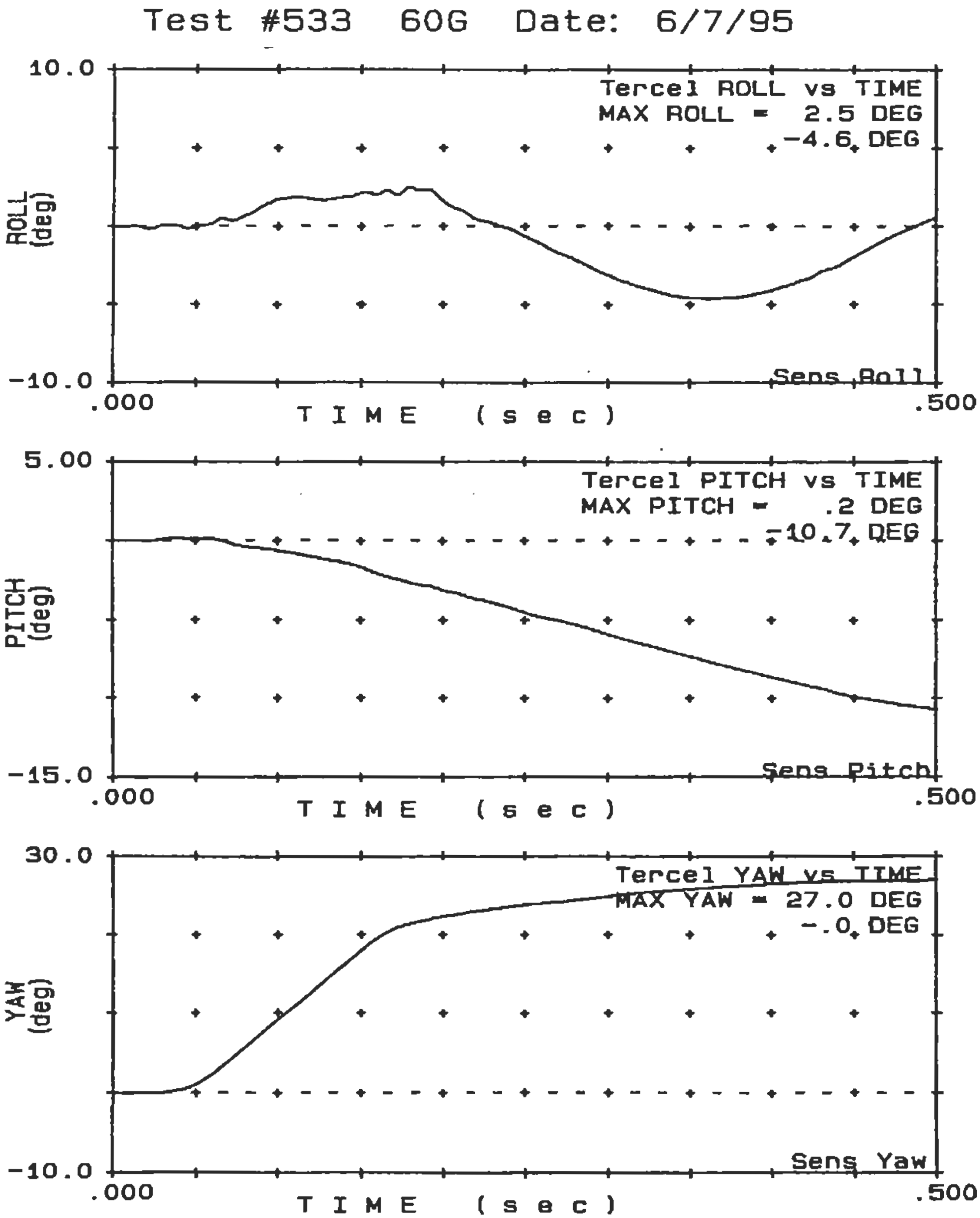


Figure 7.13 - Test 533 Dummy Head Accelerations -vs- Time

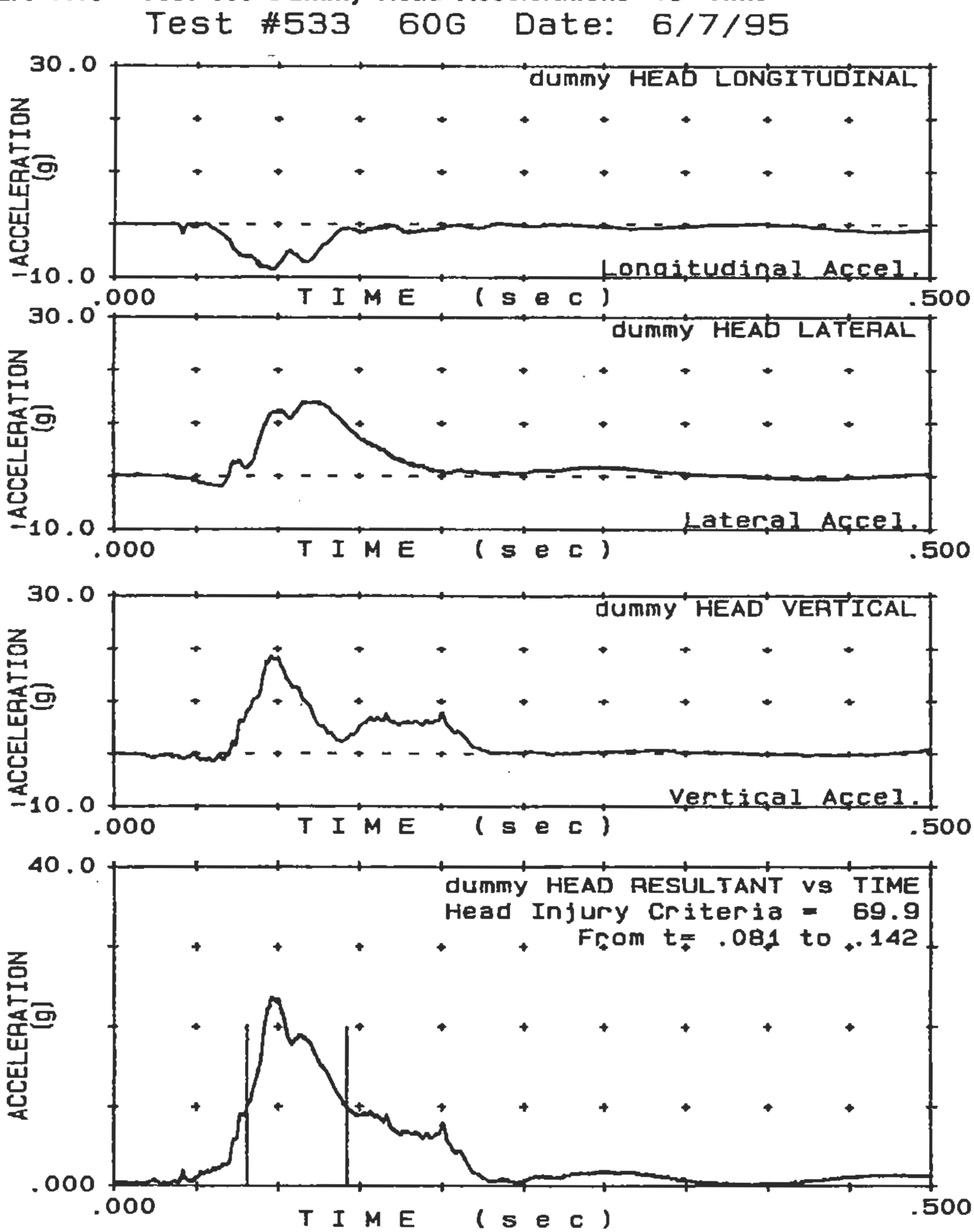


Figure 7.14 - Test 534 Vehicle Accelerations -vs- Time

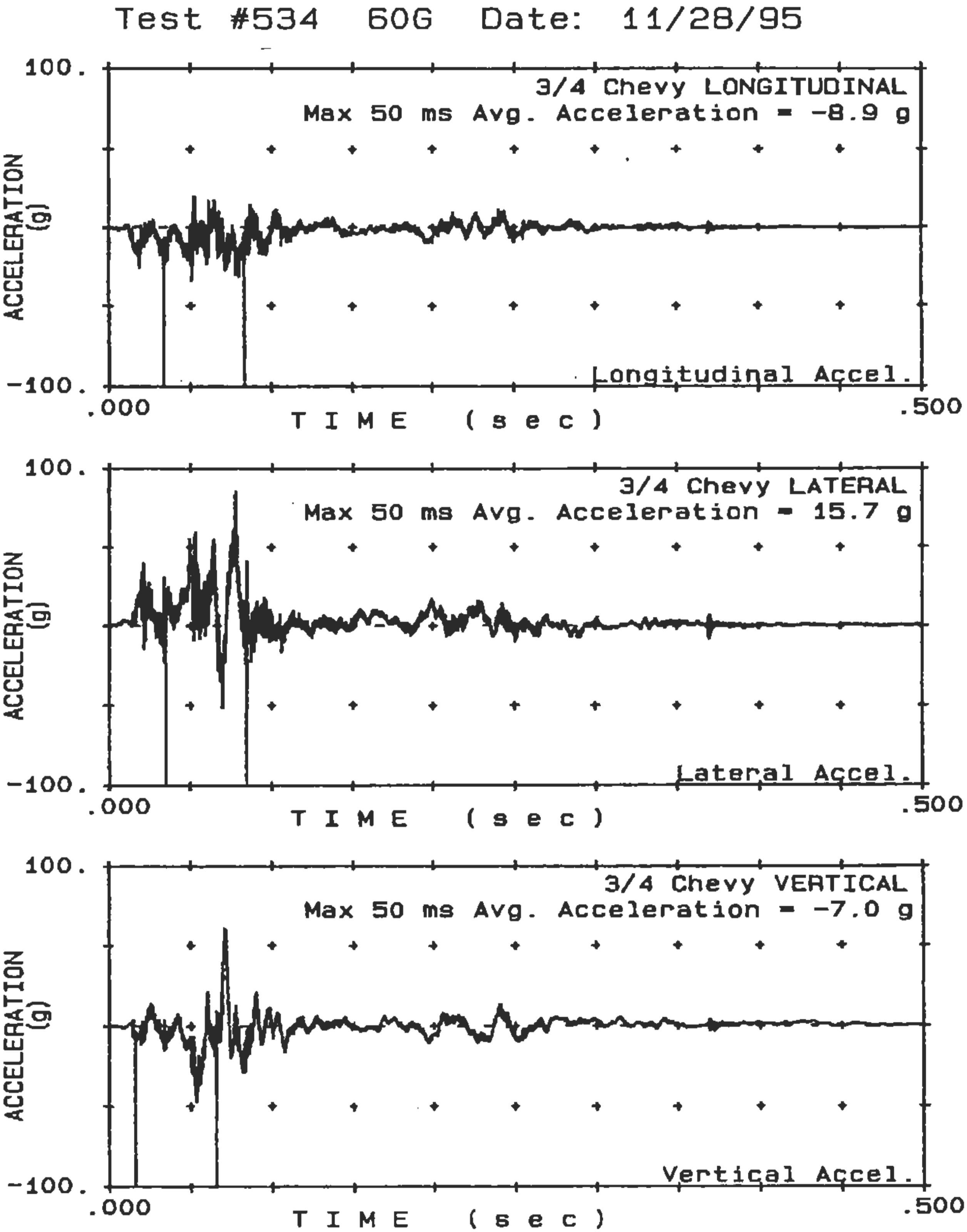


Figure 7.15 - Test 534 Vehicle Longitudinal Acceleration, Velocity and Distance -vs- Time

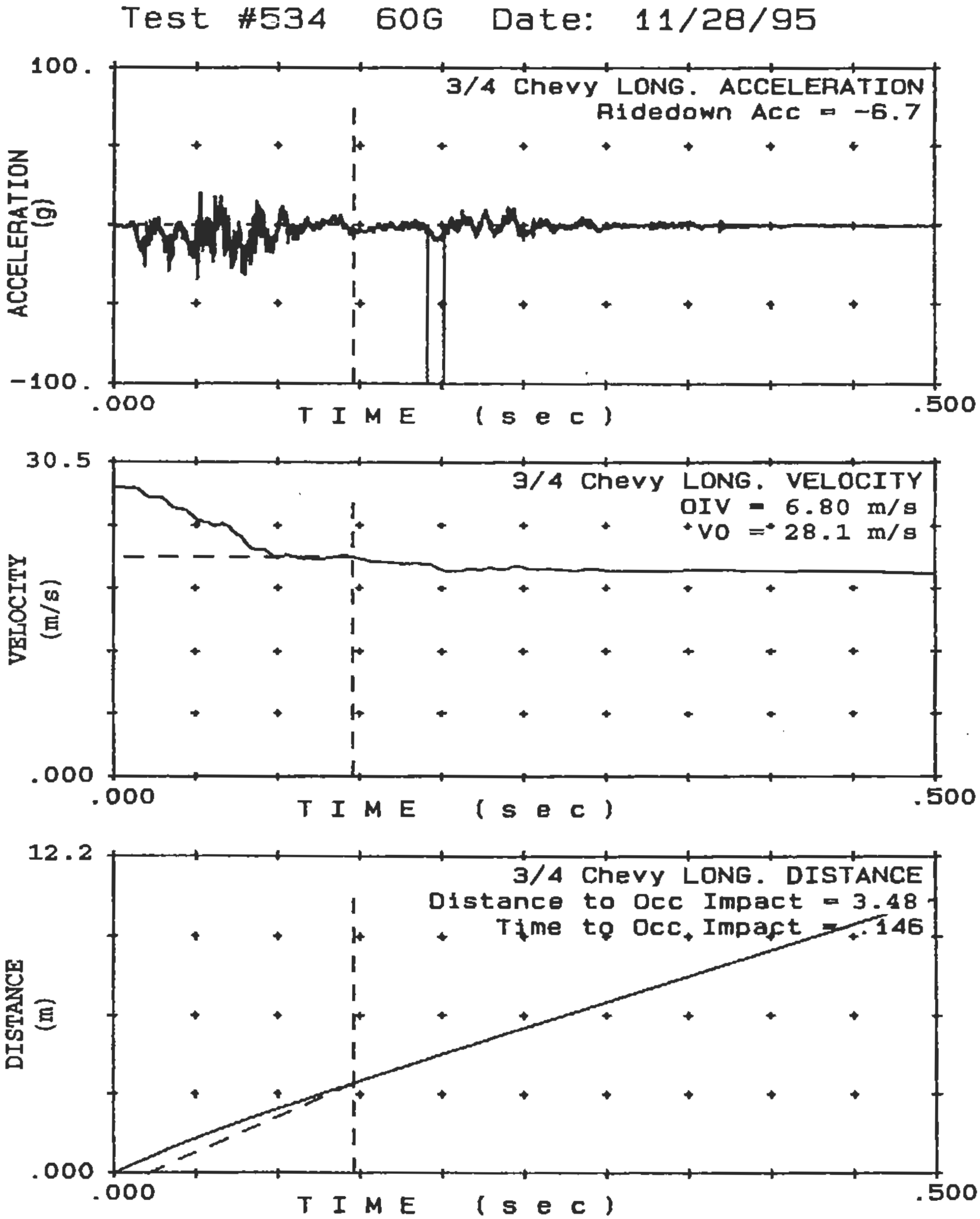


Figure 7.16 - Test 534 Vehicle Lateral Acceleration, Velocity and Distance -vs- Time

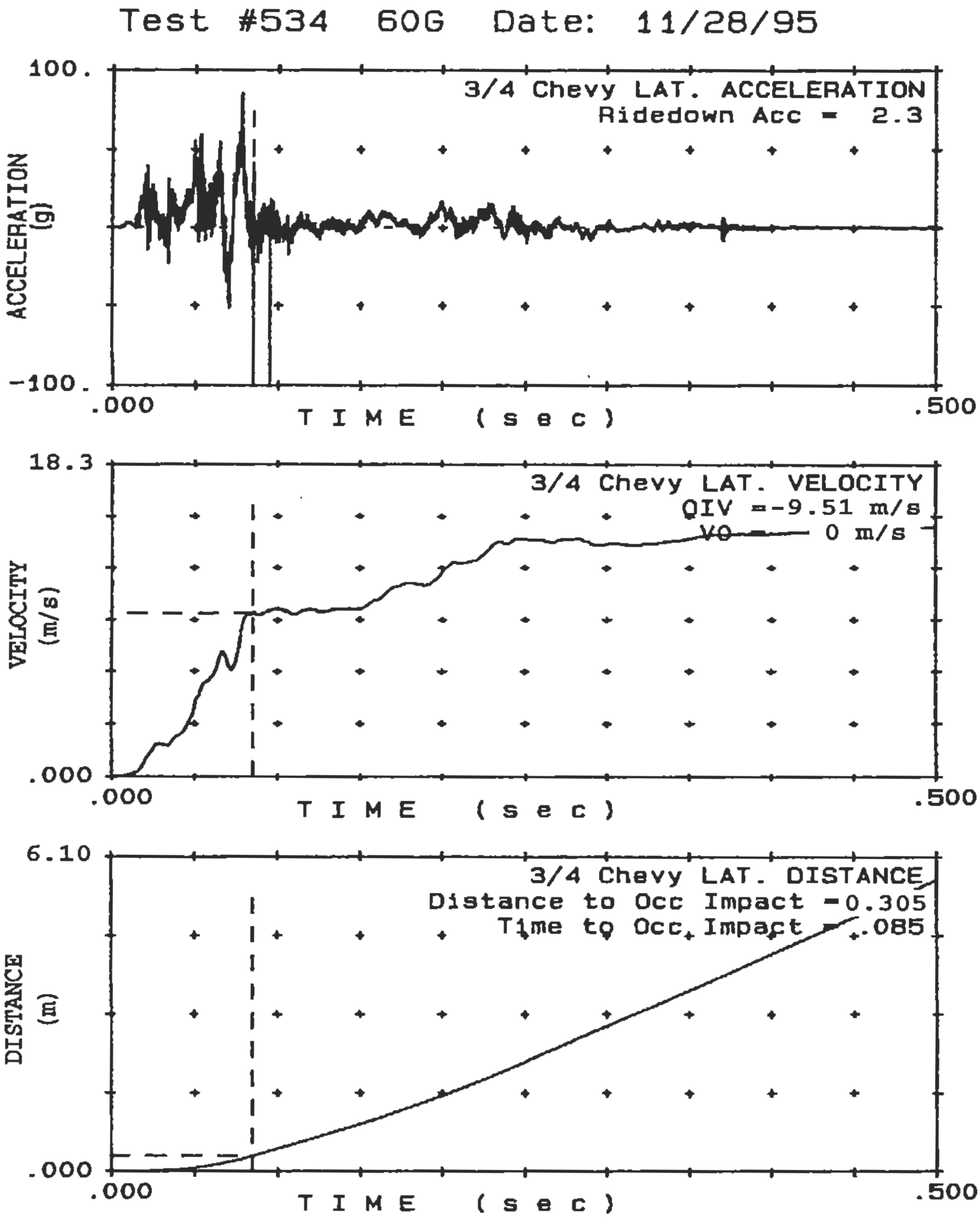


Figure 7.17 - Test 534 Vehicle Roll, Pitch and Yaw -vs- Time

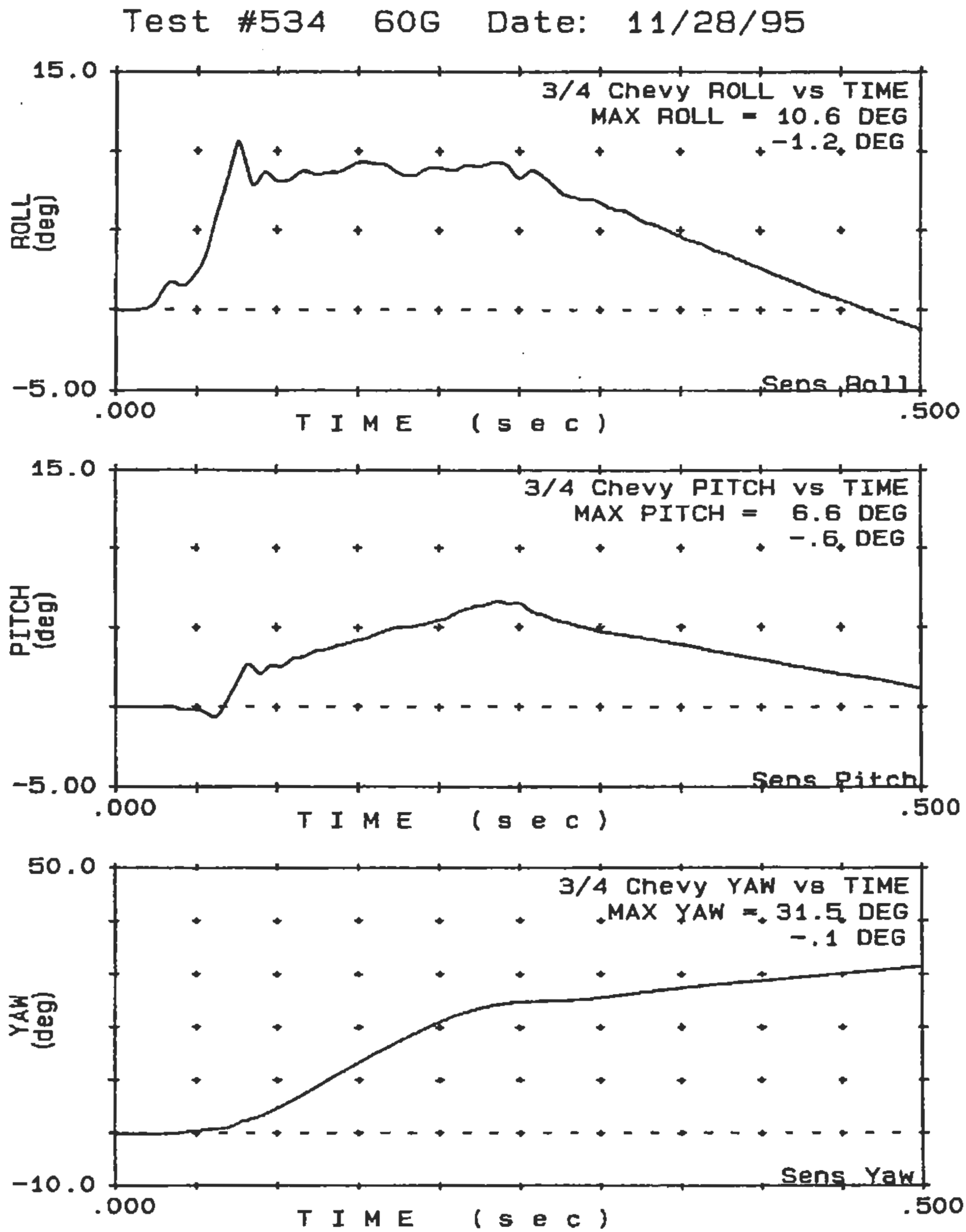


Figure 7.18 - Test 511 Vehicle Accelerations -vs- Time

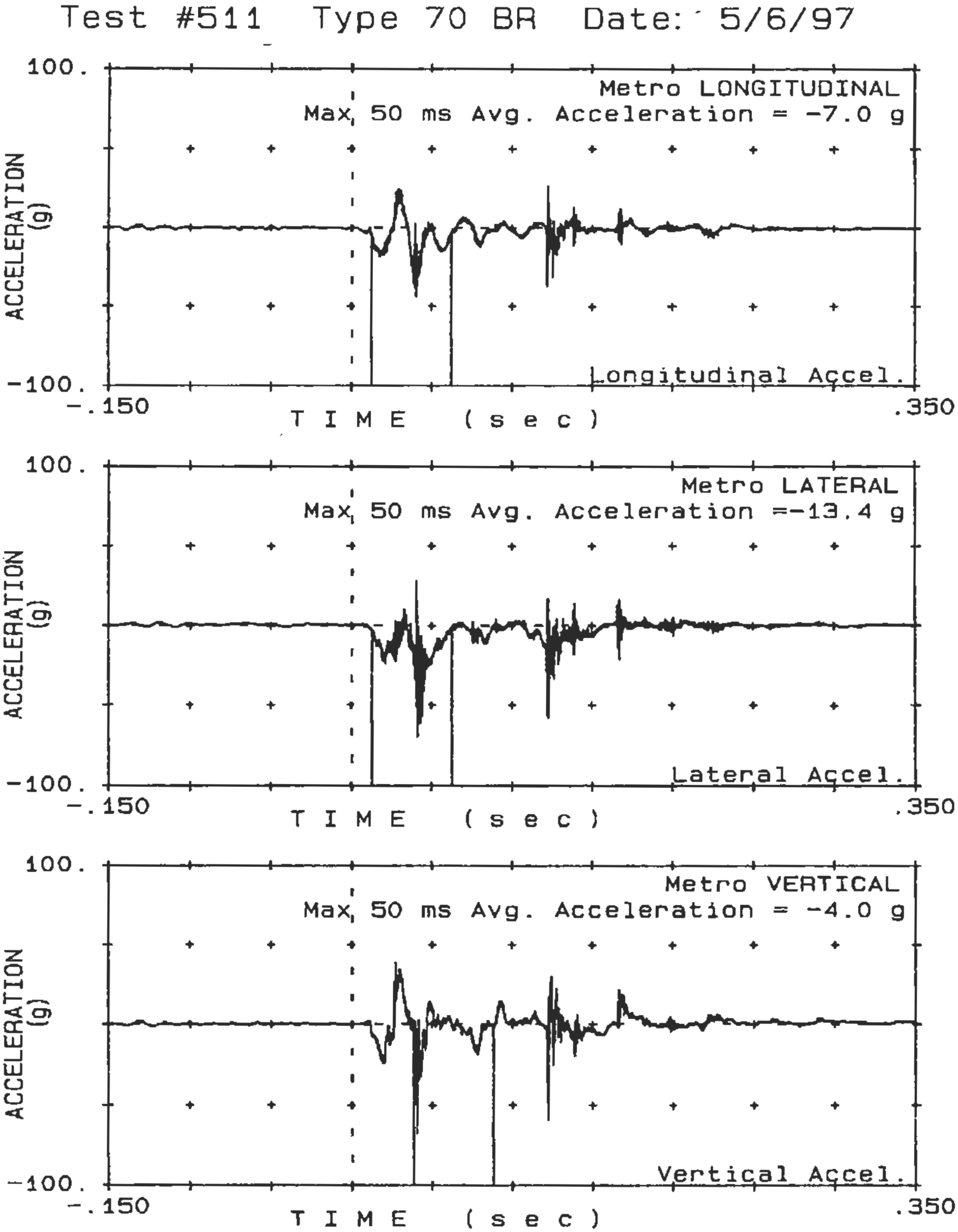


Figure 7.19 - Test 511 Vehicle Longitudinal Acceleration, Velocity and Distance -vs- Time

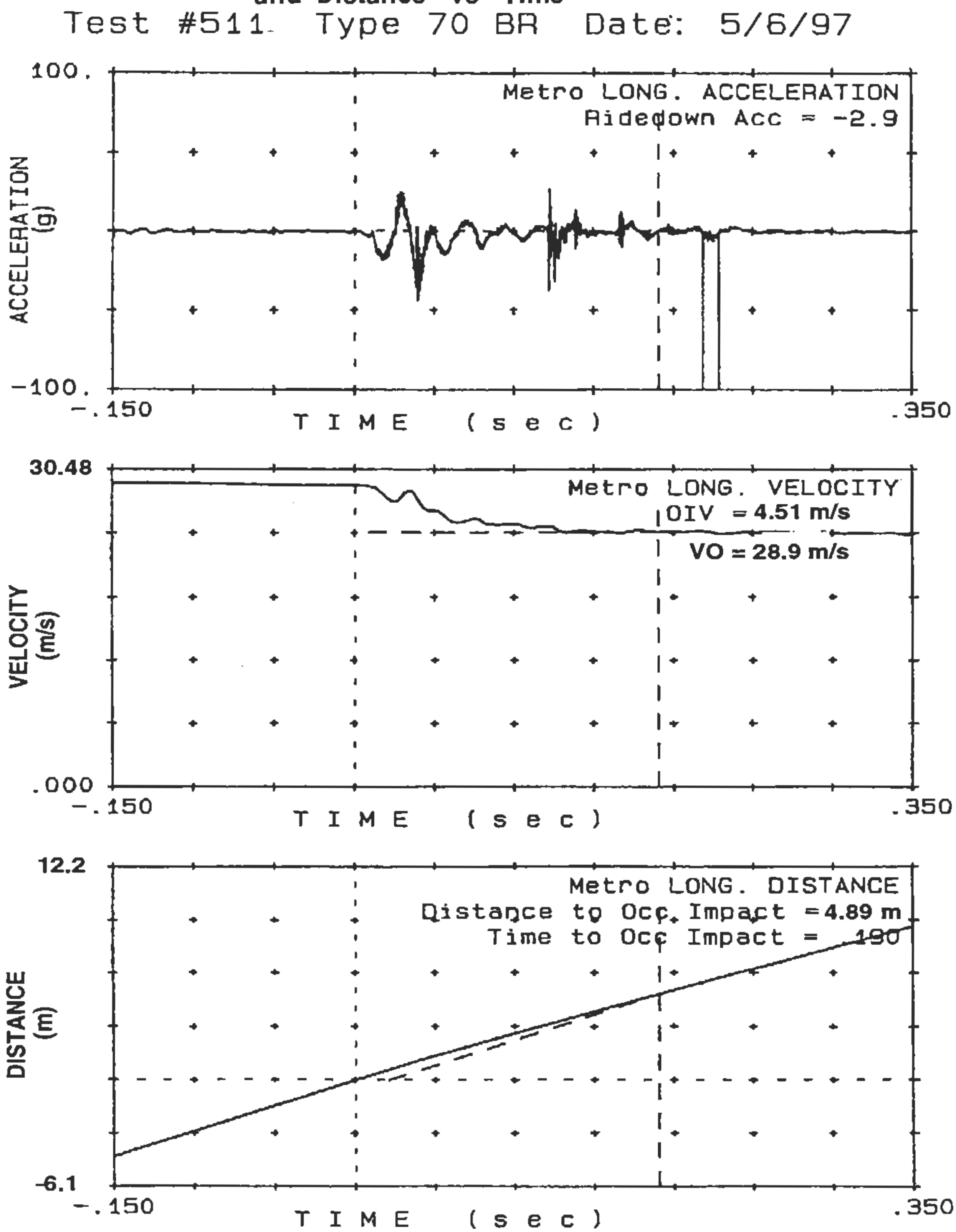


Figure 7.20 - Test 511 Vehicle Lateral Acceleration, Velocity and Distance -vs- Time

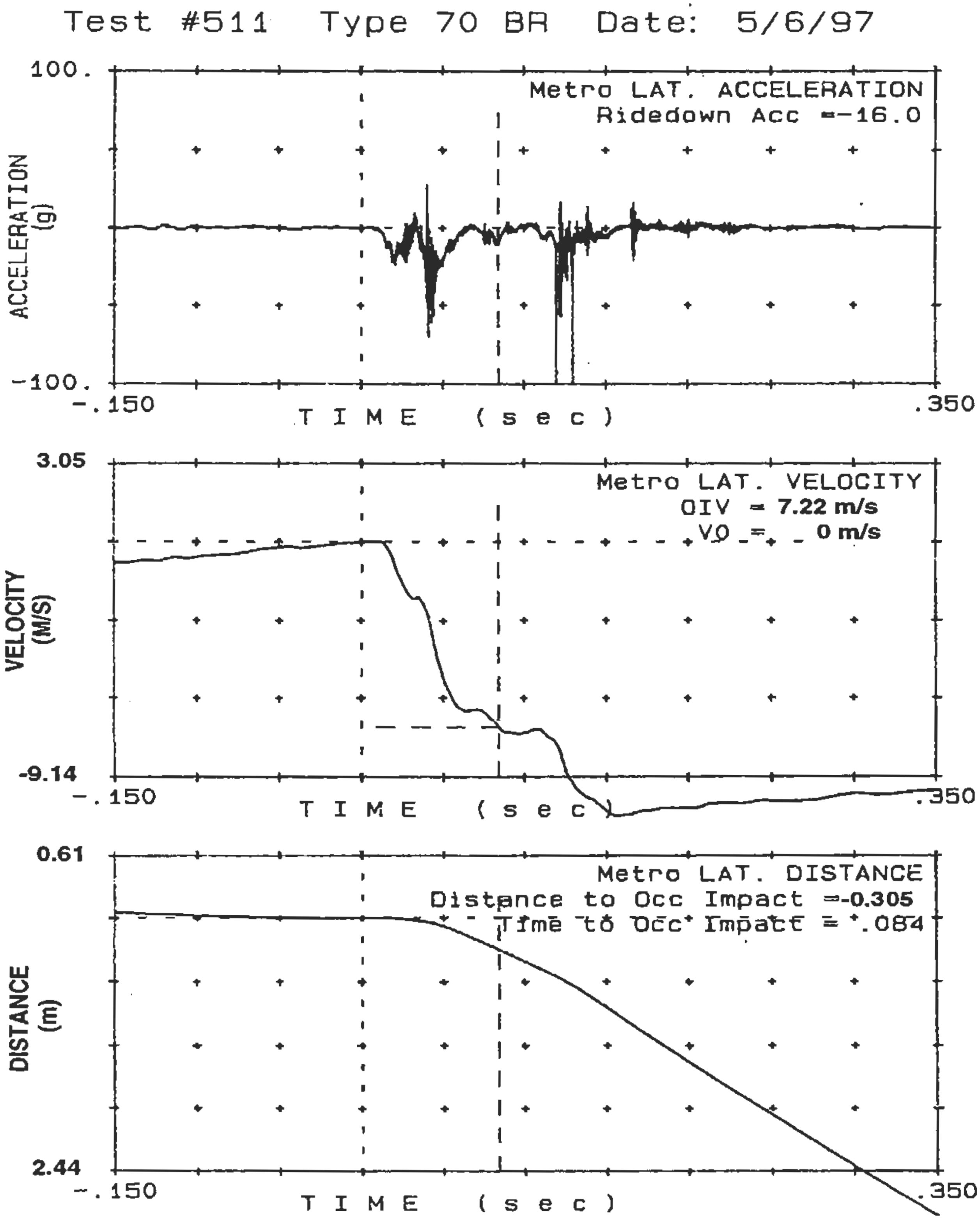


Figure 7.21 - Test 511 Vehicle Roll, Pitch and Yaw -vs- Time

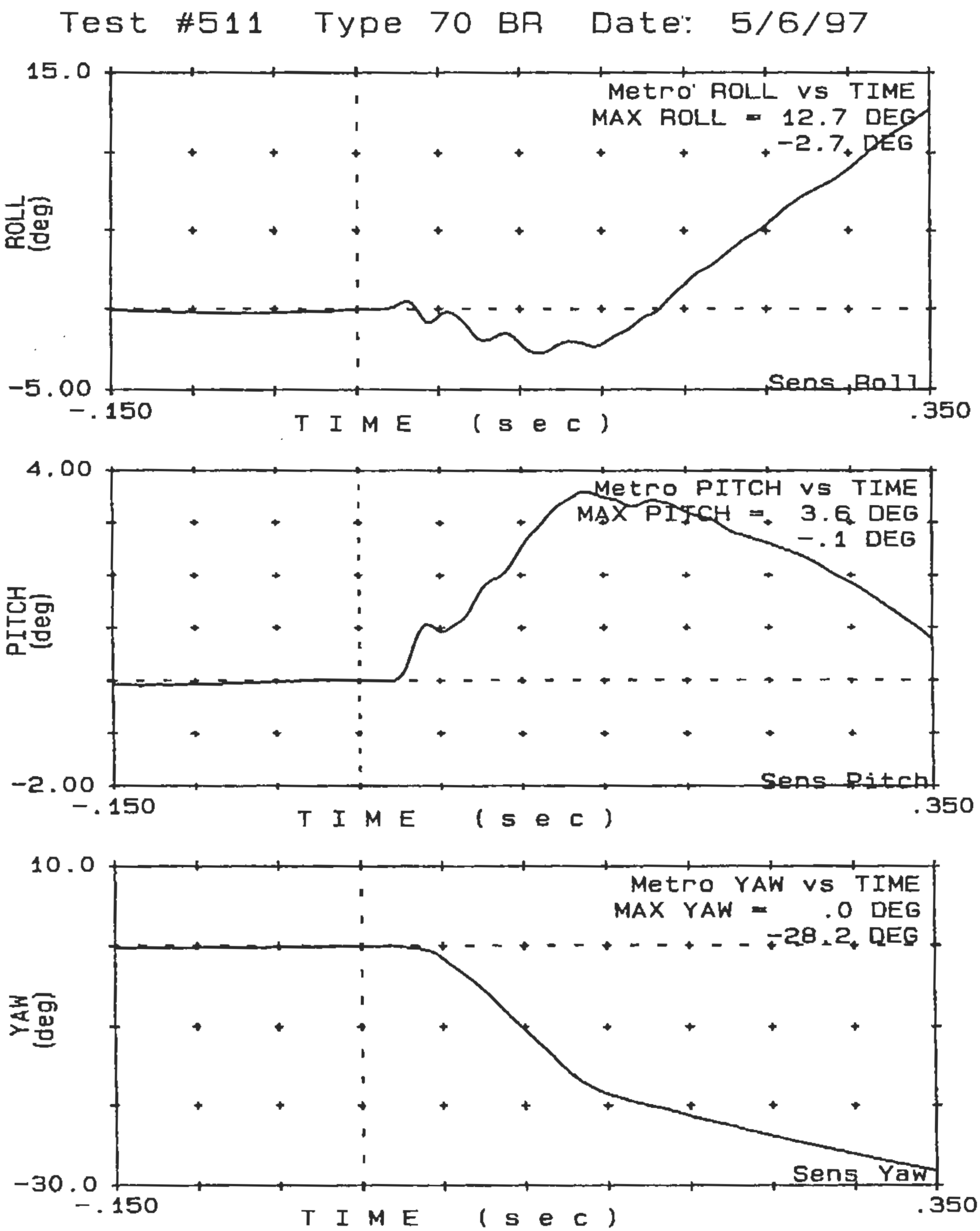
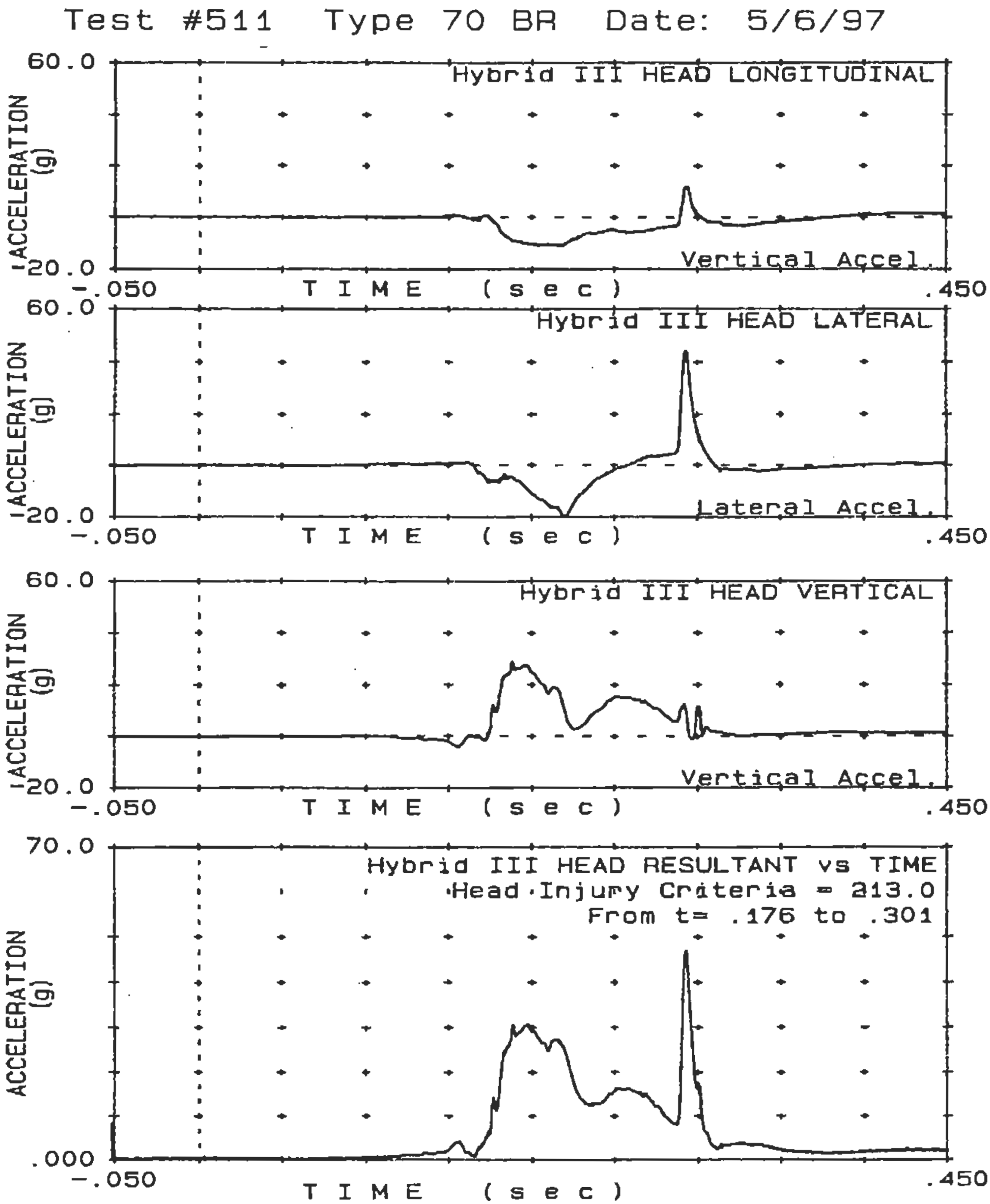


Figure 7.22 - Test 511 Dummy Head Accelerations -vs- Time



7.5. *Barrier Profile*

During the construction phase of the project, it was determined that the barriers were going to slump into a shape that would not correspond well to the design angles of 9.1 and 10.8 degrees. It was decided that the barrier profiles would be measured for their accuracy.

Measurements made using a vertical pole that was placed next to the barriers at regular intervals both longitudinally and vertically. Table 7-8 and Table 7-9 contain the data from those measurements. Figure 7.23 shows the relative slopes of the barrier at the locations where the crash tests took place. It should be noted that the slopes of the barriers are within one degree of their intended angles at the elevations where the vehicles made contact with the barriers.

Table 7-8 - 60G Profile Measurements

60 G barrier measurements taken by N. Khan and J. Jewell 3-6-95.

Height	0 ft	10 ft	20 ft	30 ft	40 ft	50 ft	60 ft	70 ft	80 ft	90 ft	100 ft	110 ft	120 ft	130 ft	140 ft	150 ft
57	10.9	10.4	11.9	10.9	9.8	10.6	10.3	11.1	11.3	10.1	10.6	12.0	11.0	10.9	12.3	11.9
50	9.6	9.1	10.8	9.8	8.5	9.8	9.3	10.0	10.0	9.0	9.5	10.6	9.9	9.8	10.8	10.8
40	7.8	7.0	9.3	8.3	6.9	8.0	7.5	8.3	8.3	7.5	8.8	9.0	8.3	8.1	9.1	8.8
30	6.0	5.1	7.6	6.5	5.1	6.1	5.8	6.5	6.4	5.8	6.0	7.3	6.1	6.1	7.4	6.8
20	4.1	3.1	6.0	5.0	3.5	4.4	3.9	4.8	4.6	4.0	4.5	5.8	3.4	4.4	5.4	5.1
10	2.3	1.8	4.4	3.3	2.0	2.6	2.1	3.1	2.8	2.3	2.5	4.0	2.5	2.5	3.5	3.6
0	0.8	1.1	2.8	2.0	0.9	1.4	1.0	2.0	1.6	1.0	1.4	3.0	1.1	1.3	2.1	2.8
Height	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.8	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7

Make top of barrier the zero point.

57	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	1.3	1.3	1.1	1.1	1.3	0.9	1.0	1.1	1.3	1.1	1.1	1.4	1.1	1.1	1.5	1.1
40	3.1	3.4	2.6	2.6	2.9	2.6	2.8	2.9	3.0	2.6	1.8	3.0	2.8	2.8	3.1	3.1
30	4.9	5.3	4.3	4.4	4.6	4.5	4.5	4.6	4.9	4.4	4.6	4.8	4.9	4.8	4.9	5.1
20	6.8	7.3	5.9	5.9	6.3	6.3	6.4	6.4	6.6	6.1	6.1	6.3	7.6	6.5	6.9	6.8
10	8.6	8.6	7.5	7.6	7.8	8.0	8.1	8.0	8.5	7.9	8.1	8.0	8.5	8.4	8.8	8.3
0	10.1	9.3	9.1	8.9	8.9	9.3	9.3	9.1	9.6	9.1	9.3	9.0	9.9	9.6	10.1	9.1

Make 30 inches the zero point.

57	-4.9	-5.3	-4.3	-4.4	-4.6	-4.5	-4.5	-4.6	-4.9	-4.4	-4.6	-4.8	-4.9	-4.8	-4.9	-5.1
50	-3.6	-3.9	-3.2	-3.3	-3.4	-3.6	-3.5	-3.5	-3.6	-3.3	-3.5	-3.4	-3.8	-3.6	-3.4	-4.0
40	-1.8	-1.9	-1.6	-1.8	-1.8	-1.9	-1.8	-1.8	-1.9	-1.8	-2.8	-1.8	-2.1	-2.0	-1.8	-2.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	1.9	2.0	1.6	1.5	1.6	1.8	1.9	1.8	1.8	1.8	1.5	1.5	2.8	1.8	2.0	1.6
10	3.8	3.4	3.3	3.3	3.1	3.5	3.6	3.4	3.6	3.5	3.5	3.3	3.6	3.6	3.9	3.1
0	5.3	4.0	4.9	4.5	4.3	4.8	4.8	4.5	4.8	4.8	4.6	4.3	5.0	4.9	5.3	4.0

Angles taken between the points.

																	ave.
50-57	10.3	10.9	8.76	9.29	10.3	7.2	8.24	9.29	10.3	9.29	9.29	11.4	9.29	9.29	12.5	9.29	*9.7*
40-50	10.9	12	9.03	8.66	9.39	10.1	10.1	10.1	10.1	8.66	3.95	9.39	9.39	9.39	9.39	11.6	*9.5*
30-40	10.1	10.9	9.39	10.1	10.1	10.9	10.1	10.1	10.9	10.1	16.6	10.1	12.4	11.6	10.1	11.6	*10.9*
20-30	10.9	11.6	9.39	8.66	9.39	10.1	10.9	10.1	10.1	10.1	8.66	8.66	16.2	10.1	11.6	9.39	*10.4*
10-20	10.9	7.93	9.39	10.1	8.66	10.1	10.1	9.39	10.9	10.1	11.6	10.1	5.03	10.9	10.9	8.66	*9.7*
0-10	8.66	3.59	9.39	7.2	6.47	7.2	6.47	6.47	6.47	7.2	6.47	5.75	7.93	7.2	7.93	5.03	*6.8*
ave.	*10.3*	*9.5*	*9.2*	*9.0*	*9.1*	*9.3*	*9.3*	*9.3*	*9.8*	*9.3*	*9.4*	*9.2*	*10.0*	*9.7*	*10.4*	*9.3*	*9.5*
max.	*10.9*	*12.0*	*9.4*	*10.1*	*10.3*	*10.9*	*10.9*	*10.1*	*10.9*	*10.1*	*16.6*	*11.4*	*16.2*	*11.6*	*12.5*	*11.6*	*10.9*
min.	*8.7*	*3.6*	*8.8*	*7.2*	*6.5*	*7.2*	*6.5*	*6.5*	*6.5*	*7.2*	*3.9*	*5.7*	*5.0*	*7.2*	*7.9*	*5.0*	*6.8*

Table 7-9 - Texas Barrier Profile Measurements

Texas Barrier measurements taken by N. Khan and J. Jewell 3-6-95.

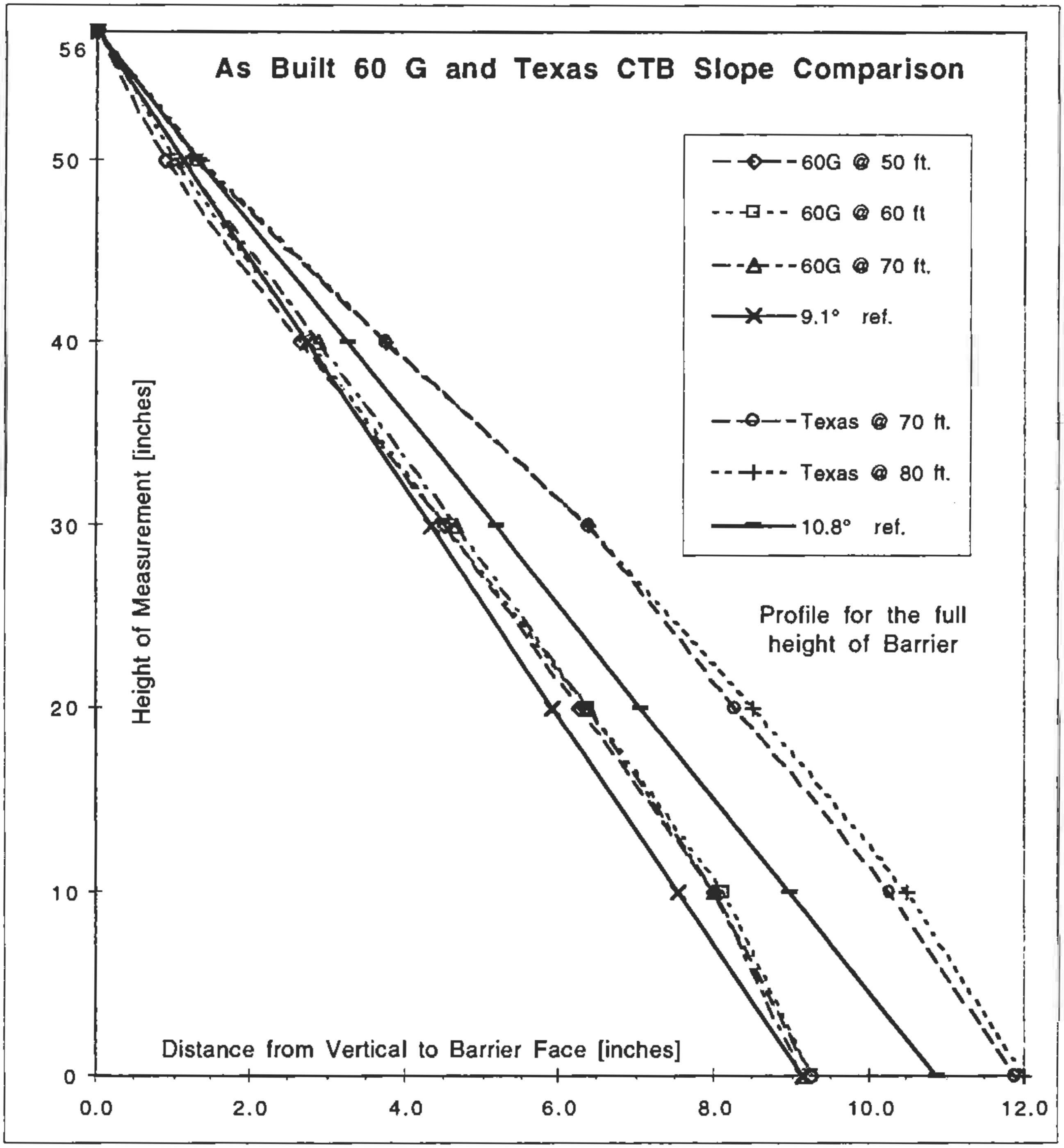
0 ft	10 ft	20 ft	30 ft	40 ft	50 ft	60 ft	70 ft	80 ft	90 ft	100 ft	110 ft	120 ft	130 ft	140 ft	150 ft
13.8	13.8	12.1	13.0	12.9	12.0	12.1	12.5	12.8	12.9	13.5	13.8	14.0	13.3	13.1	14.3
12.3	12.0	10.8	11.5	11.5	10.8	10.8	11.2	11.4	11.4	12.1	12.4	12.4	11.6	11.6	12.8
10.1	10.0	8.6	9.0	9.1	8.4	8.6	8.8	9.0	8.8	9.6	9.8	9.9	9.3	9.4	10.6
7.8	7.3	5.9	6.5	6.5	5.8	6.3	6.1	6.4	6.1	7.0	6.8	6.9	6.6	6.9	8.1
5.4	4.8	4.1	4.6	4.4	4.0	4.4	4.3	4.3	4.1	5.0	4.6	4.9	4.6	4.8	5.8
3.0	2.8	2.2	2.5	2.4	2.9	2.4	2.3	2.3	2.3	2.9	2.4	2.8	2.4	2.9	3.3
1.0	1.0	0.3	0.7	0.9	0.5	1.1	0.6	0.8	0.8	1.1	0.6	1.1	0.8	1.5	1.1
4.5	4.6	4.7	4.7	4.7	4.8	4.8	4.8	4.8	4.7	4.7	4.6	4.6	4.6	4.6	4.7

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.5	1.8	1.4	1.5	1.4	1.3	1.4	1.3	1.4	1.5	1.4	1.4	1.6	1.6	1.5	1.5
3.6	3.8	3.5	4.0	3.8	3.6	3.5	3.8	3.8	4.1	3.9	4.0	4.1	4.0	3.8	3.6
6.0	6.5	6.3	6.5	6.4	6.3	5.9	6.4	6.4	6.8	6.5	7.0	7.1	6.6	6.3	6.1
8.4	8.9	8.0	8.4	8.4	8.0	7.8	8.3	8.5	8.8	8.5	9.2	9.1	8.6	8.4	8.5
10.8	11.0	9.9	10.5	10.4	9.1	9.8	10.3	10.5	10.6	10.6	11.4	11.3	10.9	10.3	11.0
12.8	12.8	11.9	12.3	12.0	11.5	11.0	11.9	12.0	12.1	12.4	13.1	12.9	12.5	11.6	13.1

-6.0	-6.5	-6.3	-6.5	-6.4	-6.3	-5.9	-6.4	-6.4	-6.8	-6.5	-7.0	-7.1	-6.6	-6.3	-6.1
-4.5	-4.8	-4.9	-5.0	-5.0	-5.0	-4.5	-5.1	-5.0	-5.3	-5.1	-5.6	-5.5	-5.0	-4.8	-4.6
-2.4	-2.8	-2.8	-2.5	-2.6	-2.6	-2.4	-2.6	-2.6	-2.7	-2.6	-3.0	-3.0	-2.6	-2.5	-2.5
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.4	2.4	1.8	1.9	2.1	1.8	1.9	1.9	2.1	1.9	2.0	2.2	2.0	2.0	2.1	2.4
4.8	4.5	3.7	4.0	4.1	2.9	3.9	3.9	4.1	3.8	4.1	4.4	4.1	4.3	4.0	4.9
6.8	6.3	5.6	5.8	5.6	5.3	5.1	5.5	5.6	5.3	5.9	6.1	5.8	5.9	5.4	7.0

																ave.
12.5	14.6	11.4	12.5	11.4	10.3	11.4	10.9	11.4	12.5	11.4	11.4	13.5	13.5	12.5	12.5	*12.1*
12.4	11.6	12.4	14.6	13.9	13.9	12.4	14.2	13.9	15.4	14.6	15.4	14.6	13.9	13.1	12.4	*13.7*
13.9	16.2	16.2	14.6	15.4	15.4	13.9	15.4	15.4	15.8	15.4	17.7	17.7	15.4	14.6	14.6	*15.5*
13.9	14.2	10.1	10.9	12	10.1	10.9	10.9	12.4	11.2	11.6	12.7	11.6	11.6	12.4	13.9	*11.9*
13.9	12	11.2	12.4	11.6	6.47	11.6	11.6	11.6	10.9	12.4	12.7	12.4	13.1	10.9	14.6	*11.8*
11.6	10.1	11.2	10.5	9.03	13.9	7.2	9.39	8.66	8.66	10.1	10.1	9.39	9.39	7.93	12.4	*10.0*
13.0	*13.1*	*12.1*	*12.6*	*12.2*	*11.7*	*11.2*	*12.1*	*12.2*	*12.4*	*12.6*	*13.4*	*13.2*	*12.8*	*11.9*	*13.4*	*12.5*
13.9	*16.2*	*16.2*	*14.6*	*15.4*	*15.4*	*13.9*	*15.4*	*15.4*	*15.8*	*15.4*	*17.7*	*17.7*	*15.4*	*14.6*	*14.6*	*15.5*
11.6	*10.1*	*10.1*	*10.5*	*9.0*	*6.5*	*7.2*	*9.4*	*8.7*	*8.7*	*10.1*	*10.1*	*9.4*	*9.4*	*7.9*	*12.4*	*10.0*

Figure 7.23 - Barrier Profiles, As-Built



NOTE: The axis are not to scale, thus the errors are magnified.

7.6. Detailed Drawing